

LA-UR-14-23342

Approved for public release; distribution is unlimited.

Title: The Majorana Demonstrator: A search for Neutrinoless Double-delta Decay of ^{76}Ge

Author(s): Xu, Wenqin

Intended for: Seminar talk at Lab of Nuclear Science at MIT

Issued: 2014-05-12



Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

The MAJORANA Collaboration



Sanford
Underground
Research
Facility



The MAJORANA DEMONSTRATOR: A search for Neutrinoless Double-delta Decay of ^{76}Ge

Wenqin Xu

Los Alamos National Laboratory

At
Laboratory for Nuclear Science, MIT
May/20/2014

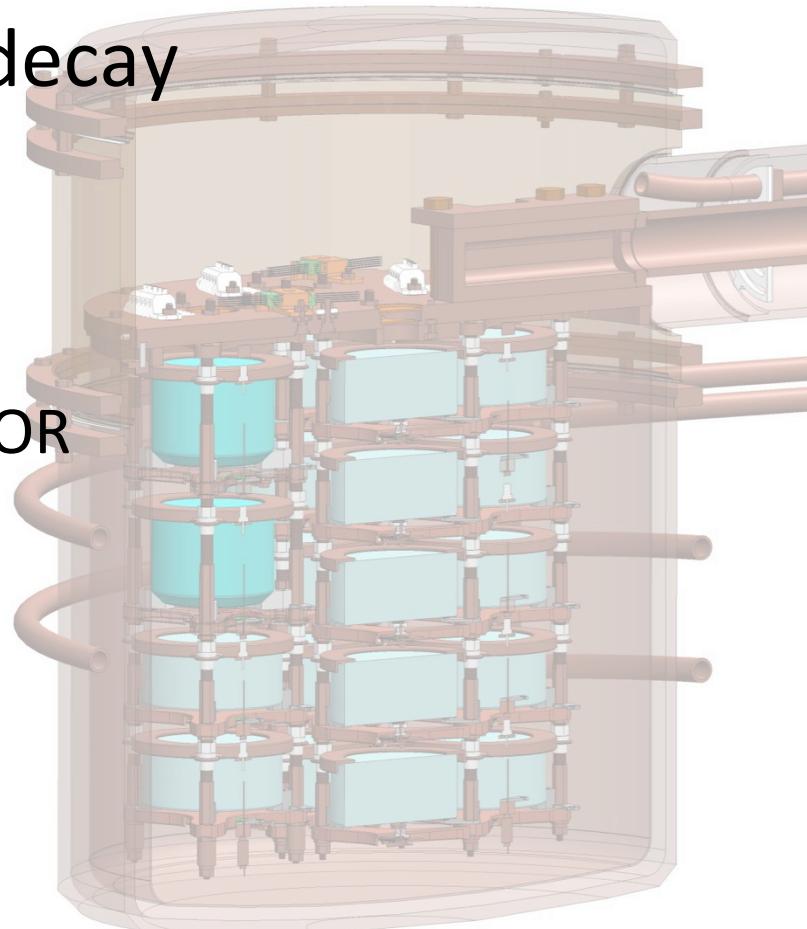


Massachusetts Institute of Technology



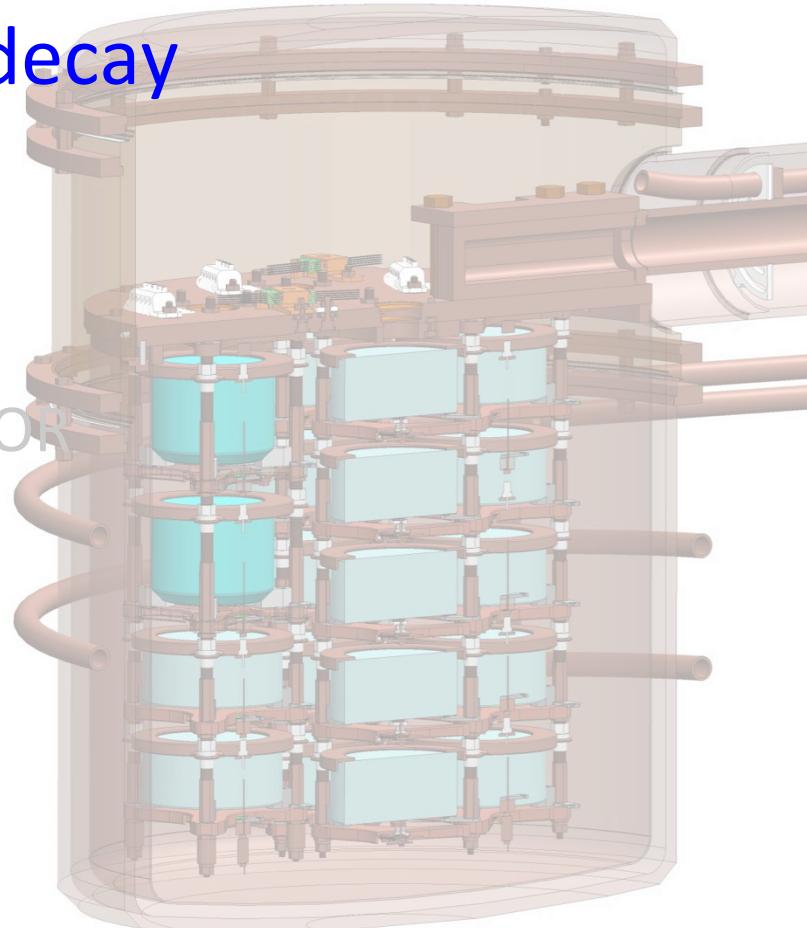
Outline of the talk

- Neutrinoless double-beta decay
 - the physics
 - the experiments
- The MAJORANA DEMONSTRATOR



Outline of the talk

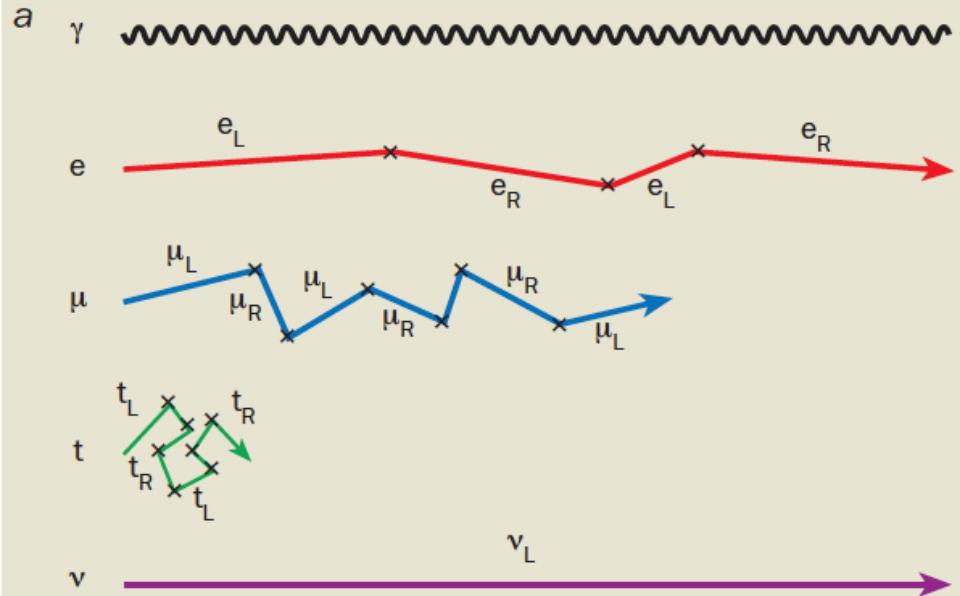
- Neutrinoless double-beta decay
 - the physics
 - the experiments
- The MAJORANA DEMONSTRATOR



Masses in the Standard Model

2 Neutrinos meet the Higgs boson

H. Murayama, Physics World, May 2002



Photons do not interact with Higgs, zero mass

Other particles collider with Higgs, flipping the handedness, acquiring masses

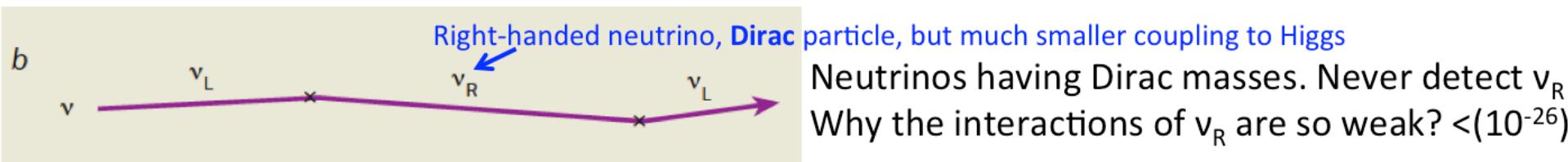
No right-handed neutrinos, no coupling to Higgs
Neutrinos should have zero mass.
But they do have non-zero mass.

Non-zero neutrino masses is the first direct indication of physics beyond the minimal standard model

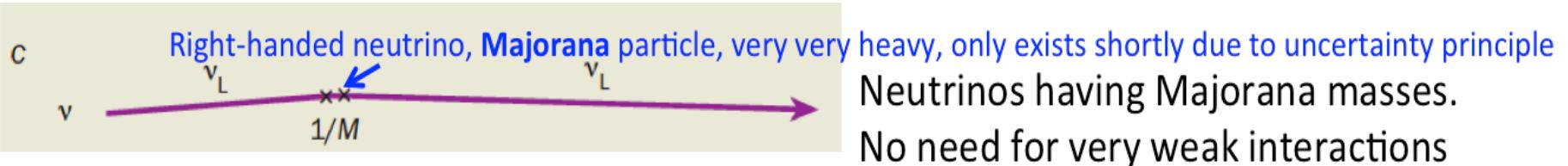
Beyond the Standard Model

2 Neutrinos meet the Higgs boson H. Murayama, Physics World, May 2002

Possible Extensions to the standard model to introduce non-zero neutrino masses:



Majorana Particle: a fermion that is its own antiparticle.



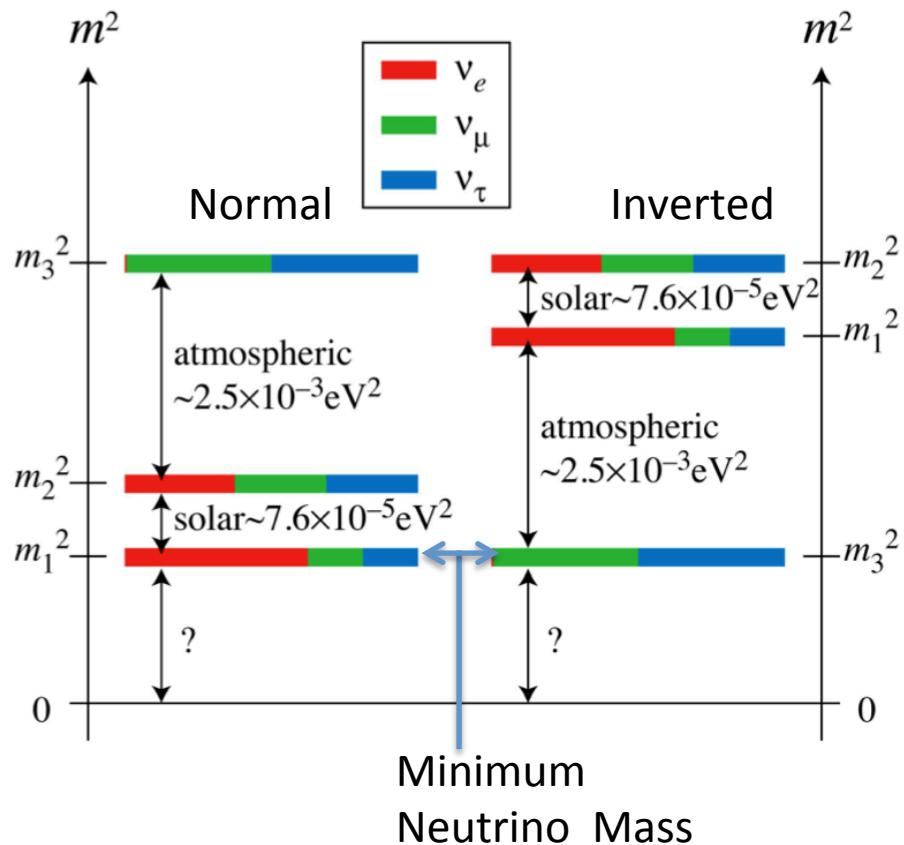
Seesaw model: An average mass m^2/M over time

Questions to be answered

Neutrinoless double beta decay:

- Is neutrino a Majorana Particle?
0νββ is the only practical way to test this.
- Is the (total) lepton number conservation violated?
- Leptogenesis as a way to produce the excess of matter?
- Neutrino mass hierarchy ?
- Absolute neutrino mass scale?

<http://hitoshi.berkeley.edu/neutrino/>

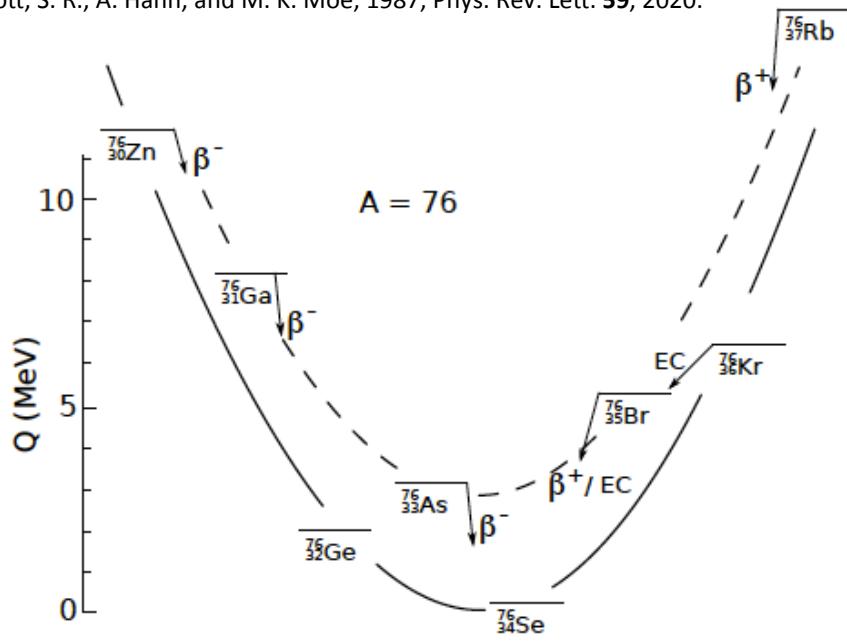


2-neutrino double beta decay

First direct observation by Steve Elliott et al in 1987

Elliott, S. R., A. Hahn, and M. K. Moe, 1987, Phys. Rev. Lett. **59**, 2020.

2nd order weak decay, very long half life

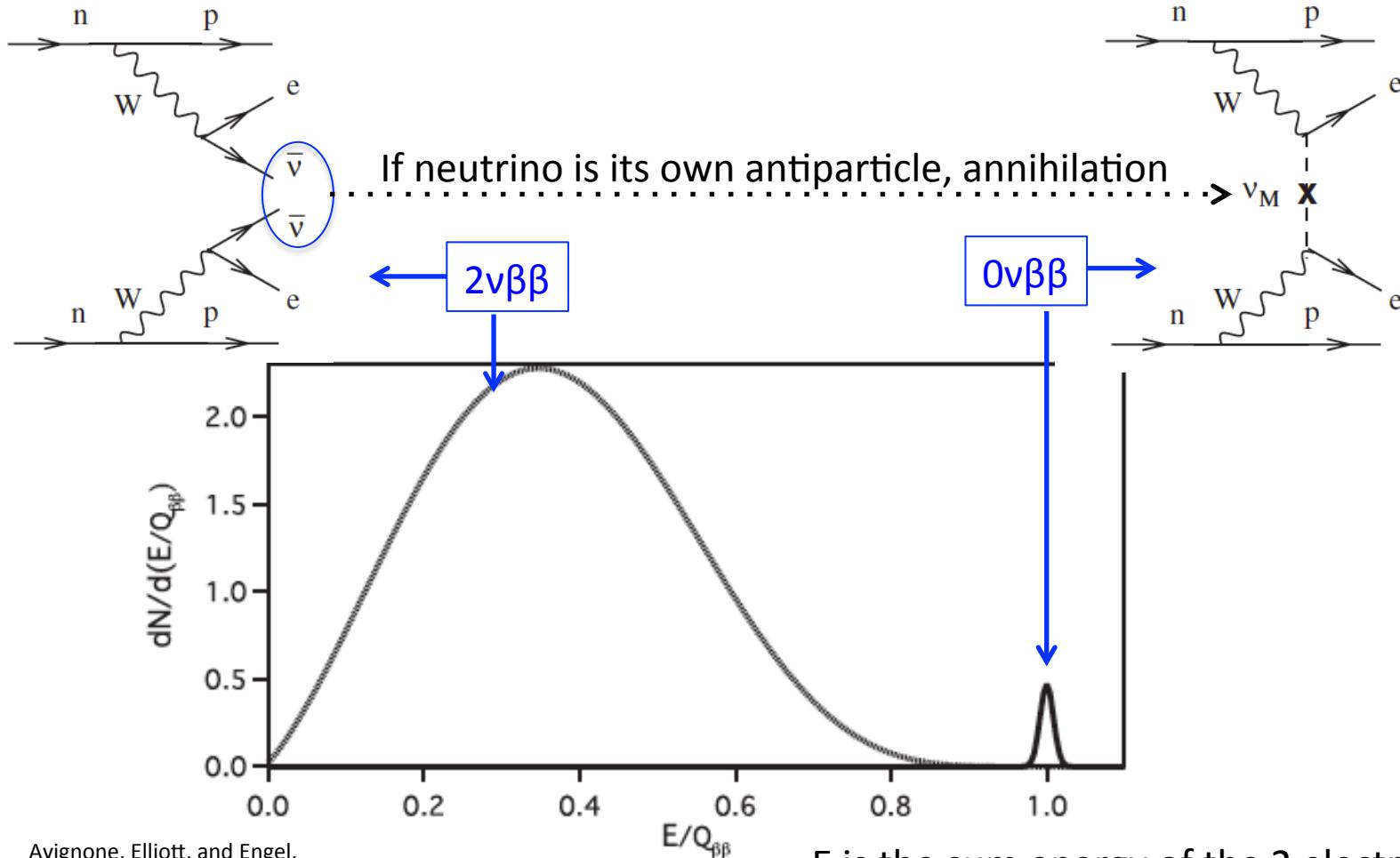


- Only possible if single beta decay is energetically forbidden.
- Observed for some nuclei with even numbers of protons and neutrons

Isotope	$T_{1/2}(2\nu)$, yr
^{48}Ca	$4.3^{+2.1}_{-1.0} \times 10^{19}$
^{76}Ge	$(1.5 \pm 0.1) \times 10^{21}$
^{82}Se	$(0.92 \pm 0.07) \times 10^{20}$
^{96}Zr	$(2.0 \pm 0.3) \times 10^{19}$
^{100}Mo	$(7.1 \pm 0.4) \times 10^{18}$
$^{100}\text{Mo}-^{100}\text{Ru}(0_1^+)$	$(6.2^{+0.9}_{-0.7}) \times 10^{20}$
^{116}Cd	$(3.0 \pm 0.2) \times 10^{19}$
^{128}Te	$(2.5 \pm 0.3) \times 10^{24}$
^{130}Te	$(0.9 \pm 0.1) \times 10^{21}$
^{150}Nd	$(7.8 \pm 0.7) \times 10^{18}$
$^{150}\text{Nd}-^{150}\text{Sm}(0_1^+)$	$1.4^{+0.5}_{-0.4} \times 10^{20}$
^{238}U	$(2.0 \pm 0.6) \times 10^{21}$
$^{130}\text{Ba}; \text{ECEC}(2\nu)$	$(2.2 \pm 0.5) \times 10^{21}$

A. S. Barabash, ISSN 1063-7788, Physics of Atomic Nuclei, 2010, Vol. 73, No. 1, pp. 162–178.

Neutrinoless double beta decay ($0\nu\beta\beta$)



Avignone, Elliott, and Engel,
Rev. Mod. Phys., Vol. 80, No. 2, April–June 2008

E is the sum energy of the 2 electrons

$0\nu\beta\beta$ half life is related to mass

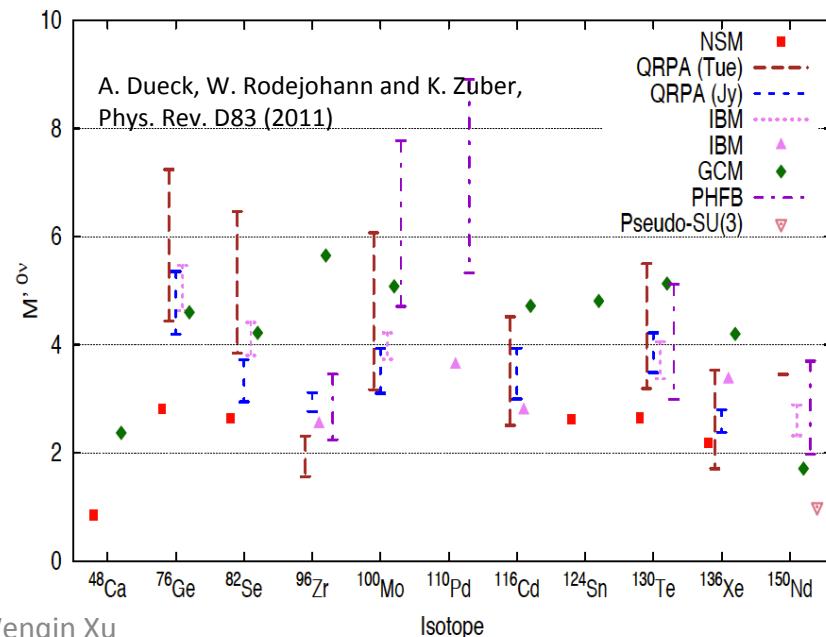
$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} |M_{0\nu}|^2 \left(\frac{\langle m_{\beta\beta} \rangle}{m_e} \right)^2$$

$\langle m_{\beta\beta} \rangle = \left| \sum_{i=1} U_{ei}^2 m_i \right|$: Effective Majorana neutrino mass

$G^{0\nu}$: Phase factor

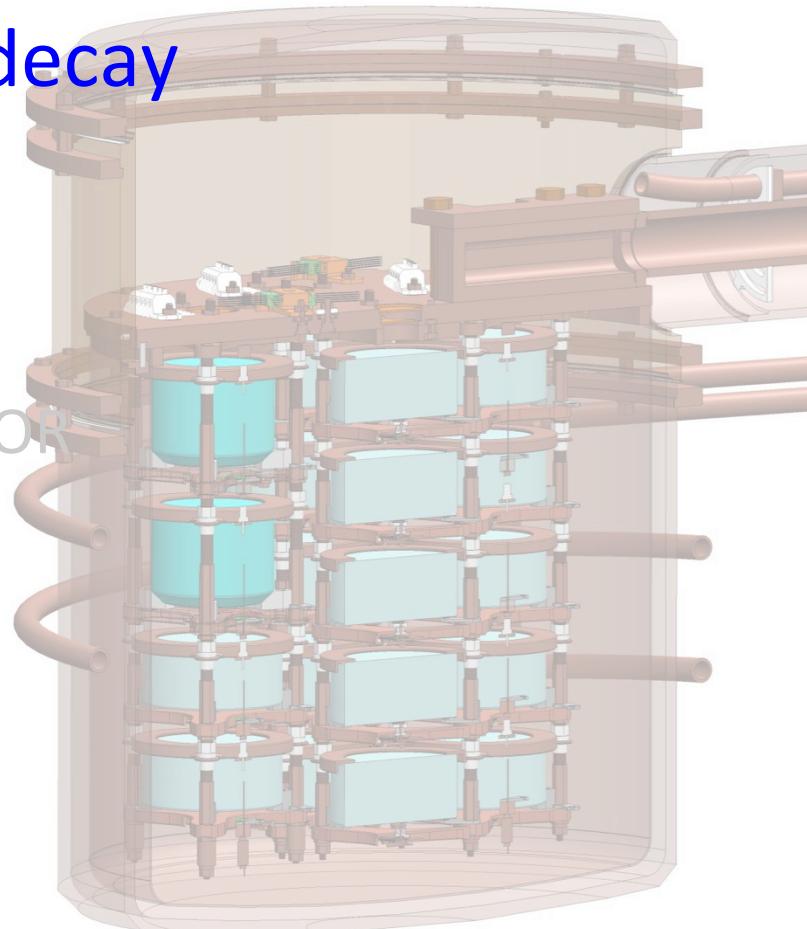
$M_{0\nu}$: Nuclear Matrix Element

Half life can be directly translated to effective majorana neutrino mass, although large uncertainties exist on NME calculation



Outline of the talk

- Neutrinoless double-beta decay
 - the physics
 - the experiments
- The MAJORANA DEMONSTRATOR



Recent List of $0\nu\beta\beta$ experiments

Isotope	$G^{0\nu}$ $\left[\frac{10^{-14}}{\text{yr}} \right]$	$Q_{\beta\beta}$ [keV]	Nat. ab. [%]	$T_{1/2}^{2\nu}$ $[10^{20} \text{ yr}]$	Experiments
^{48}Ca	6.3	4273.7	0.187	0.44	CANDLES
^{76}Ge	0.63	2039.1	7.8	15	GERDA, MAJORANA DEMONSTR.
^{82}Se	2.7	2995.5	9.2	0.92	SuperNEMO, Lucifer
^{100}Mo	4.4	3035.0	9.6	0.07	MOON, AMoRe
^{116}Cd	4.6	2809.1	7.6	0.29	Cobra
^{130}Te	4.1	2530.3	34.5	9.1	CUORE
^{136}Xe	4.3	2457.8	8.9	21	EXO, Next, Kamland-Zen
^{150}Nd	19.2	3367.3	5.6	0.08	SNO+, DCBA/MTD

B. Schwingenheuer, Ann. Phys. (Berlin) 525, No. 4 (2013)

The Choice of Ge

[Steven R. Elliott, Petr Vogel, Ann.Rev.Nucl.Part.Sci.52:115-151,2002](#)

Excellent energy resolution: crucial in distinguishing
2νββ (the ultimate background) from 0νββ near the end point

$F = \frac{7Q\delta^6}{m_e}$ is roughly the fraction of 2νββ decays ends up in the 0νββ peak region, $\delta = \Delta E/Q$

$\frac{S}{B} = \frac{m_e}{7Q\delta^6} \frac{\Gamma_{0\nu}}{\Gamma_{2\nu}} = \frac{m_e}{7Q\delta^6} \frac{T_{1/2}^{2\nu}}{T_{1/2}^{0\nu}}$. depends on the half life of 2νββ and 0νββ, element dependent

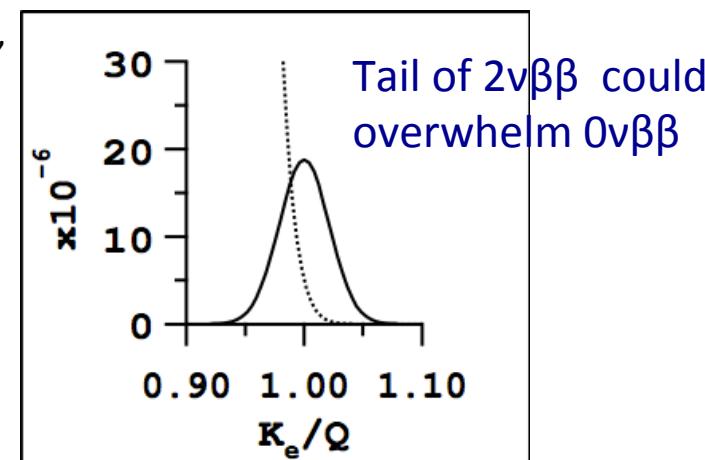
Half life ratio and $(\Delta E)^6$ decides the S/B, $\Gamma_{0\nu}=1e-6 \Gamma_{2\nu}$ →
thus the ultimate sensitivity.

ΔE is crucial

Ge detector has $\Delta E/E \sim 0.2\%$ at $Q_{\beta\beta}$

i.e. 4 keV Region of Interest (ROI) @ 2039 keV

2νββ is estimated to be negligible of the final
background in ROI for the DEMONSTRATOR



Good reasons for Ge

- ✓ Excellent Energy resolution ($\sim 0.2\%$ at 2039keV)
- ✓ Source is detector
- ✓ Can be enriched in ^{76}Ge to 86%
- ✓ Low level of radio-impurities can be achieved during processing
- ✓ Technology is well understood
- ✓ Easy to operate (LN temperature, volume is small)
- ✓ Large Q-value puts $0\nu\beta\beta$ peak above most backgrounds

Previous Ge experiments

The lower limits on $0\nu\beta\beta$ half-life:

Heidelberg-Moscow:

$T_{1/2}({}^{76}\text{Ge}) > 1.9 \times 10^{25}$ years (90% CL)

Eur. Phys. J. A. 12, 147-154 (2001)

IGEX (International Germanium Experiment):

$T_{1/2}({}^{76}\text{Ge}) > 1.57 \times 10^{25}$ years (90% CL)

Phys. Rev. D, 65, 092007 (2002)

They are the most sensitive limits until recently.

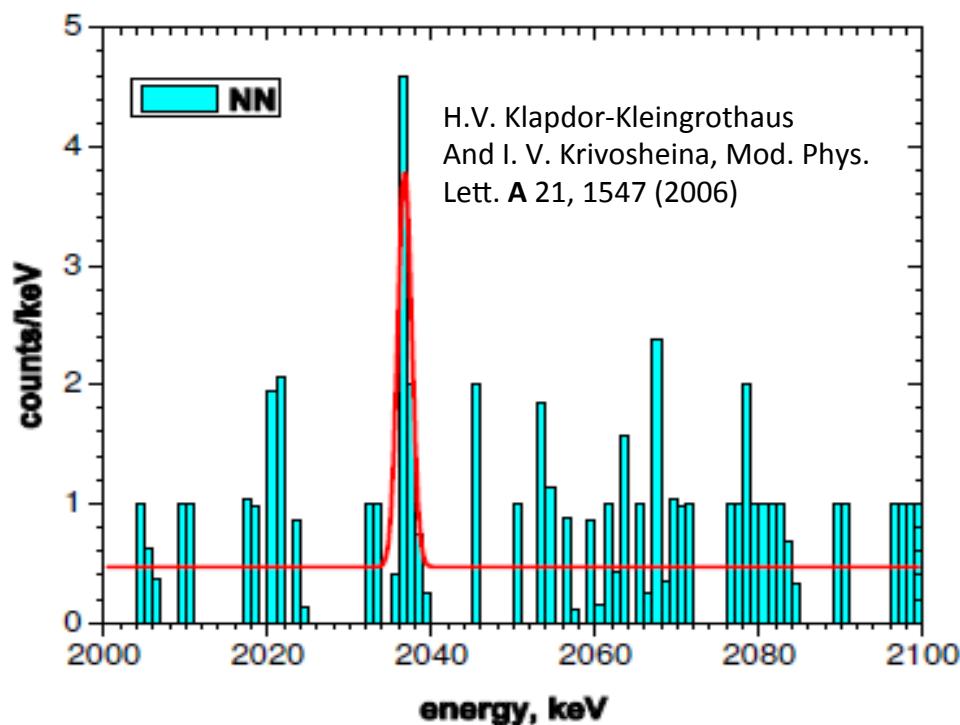
The claims:

The (2004) 4.2σ $0\nu\beta\beta$ claim: $T_{1/2} = 1.19^{+0.38}_{-0.22} \times 10^{25}\text{y}$

Total exposure $71.8\text{kg}^*\text{yr}$

H.V. Klapdor-Kleingrothaus, et al, PLB 586 (2004) 198-212

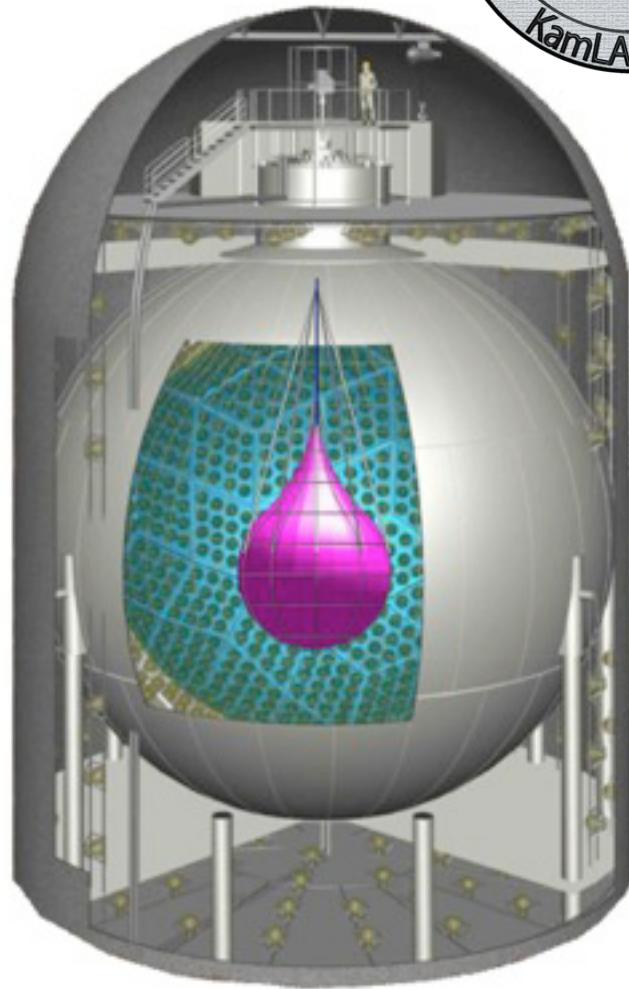
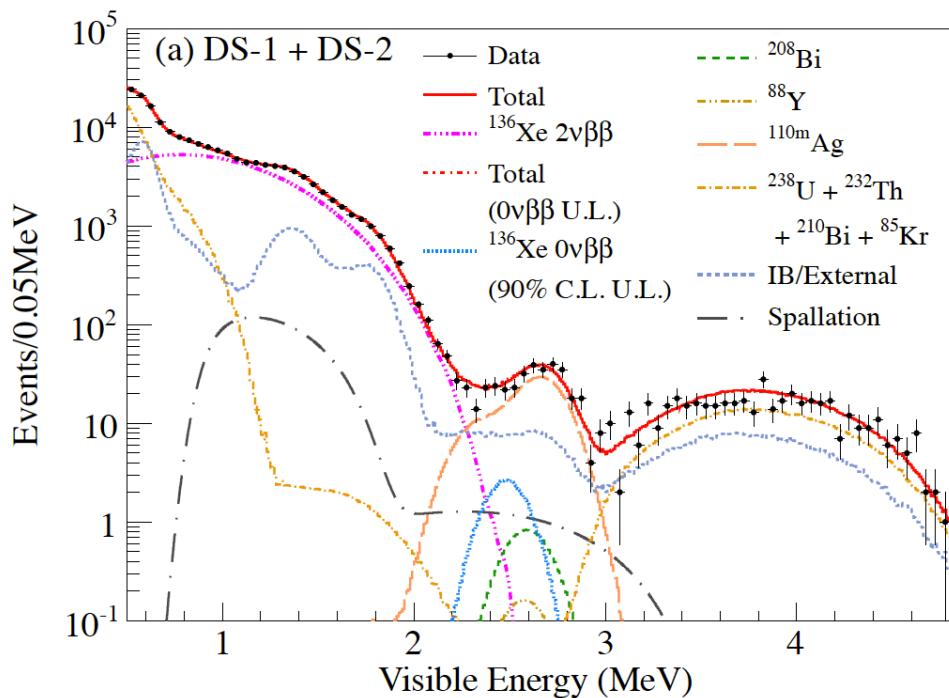
The (2006) 6.4σ $0\nu\beta\beta$ claim: $T_{1/2} = 2.23^{+0.44}_{-0.31} \times 10^{25}\text{y}$



Non-Ge: KamLAND-Zen



KamLAND-Zen: $T_{1/2}^{({}^{136}\text{Xe})} > 1.9 \times 10^{25}$ years (90% CL)
Phys.Rev.Lett. 110, 062502 (2013)

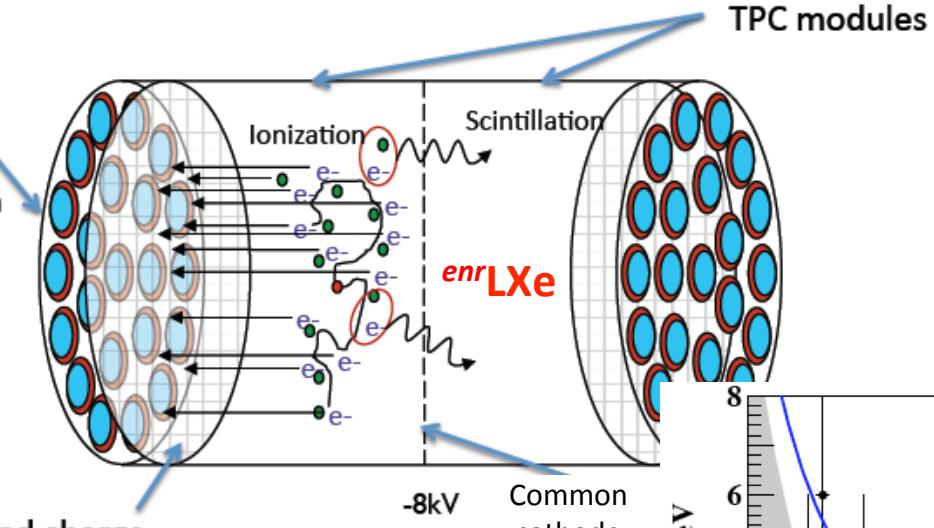


Figures adapted from:
Patrick Decowski, TAUP2013

Non-Ge: EXO-200

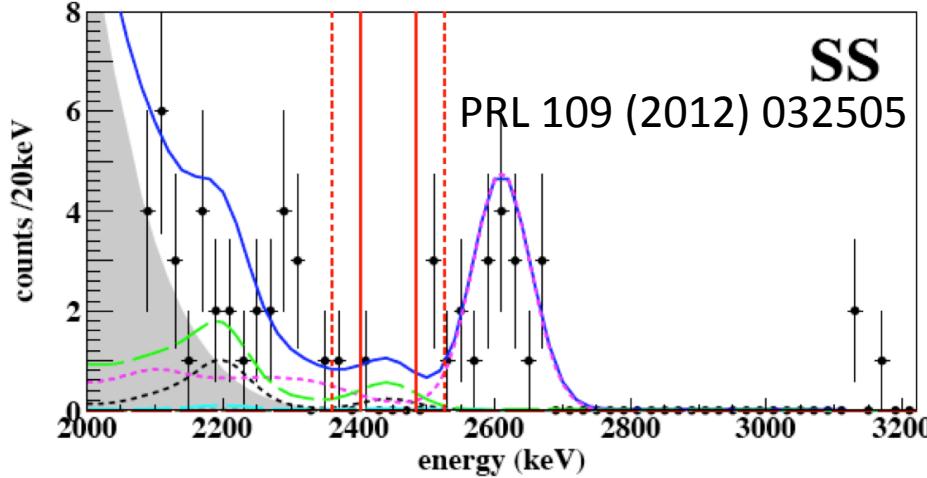


Avalanche photodiode (APD) array observes prompt scintillation



Crossed shielding and charge collection grids give x,y position

Figures adapted from:
Tim Daniels, TAUP2013

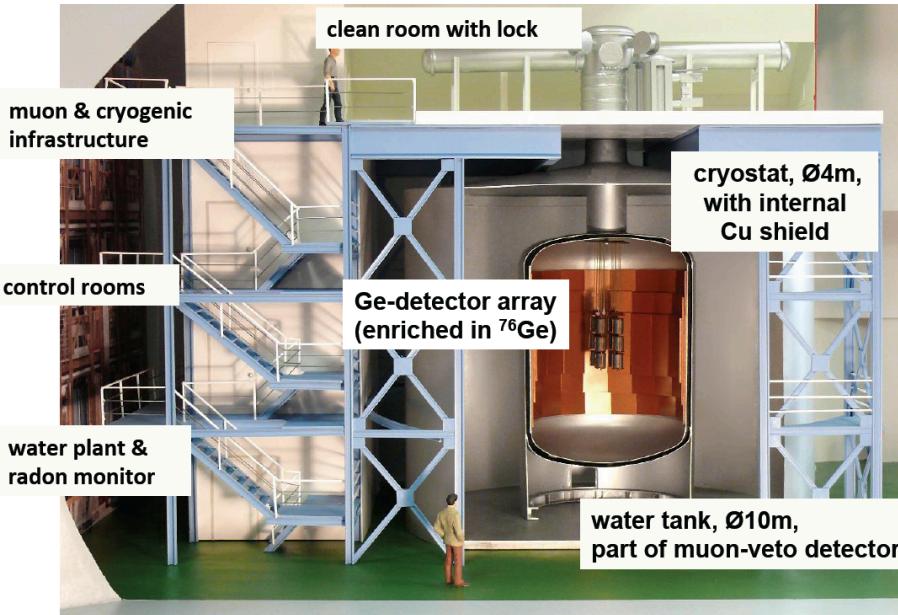


Latest EXO-200 Limit:
 $T_{1/2} (^{136}\text{Xe}) > 1.1 * 10^{25}$ year at 90% CL
 arXiv: 1402.6956 (2014)

Now: GERDA & MAJORANA DEMONSTRATOR

Figure adapted from: Stefan Schönert
(for the GERDA collaboration) LNGS Seminar, July 16, 2013

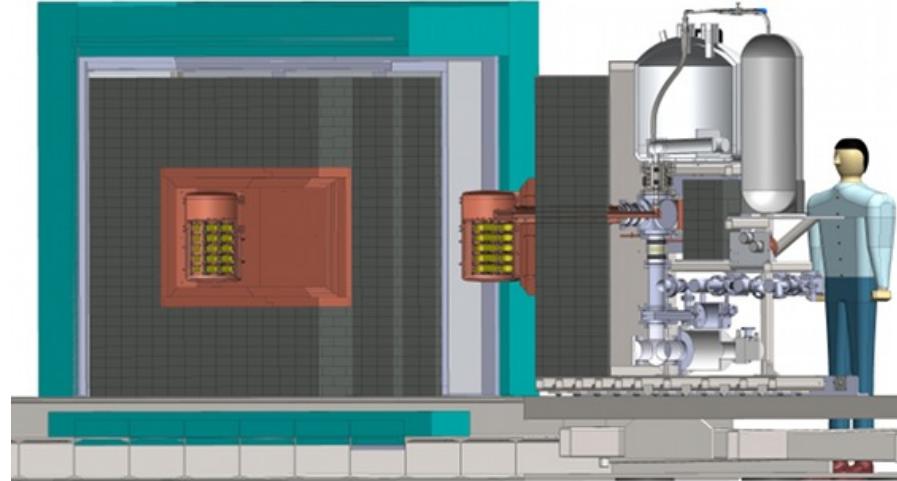
Eur. Phys. J. C (2013) 73:2330
[arXiv:1212.4067](https://arxiv.org/abs/1212.4067)



GERDA

(Germanium Detector Array)

Detectors inside a liquid argon shield
high-Z material budget is small,
relaxing depth requirement



MAJORANA DEMONSTRATOR

Detectors are inside layers of compact shield
Effectively shield against natural radioactivity



GERDA phase I results

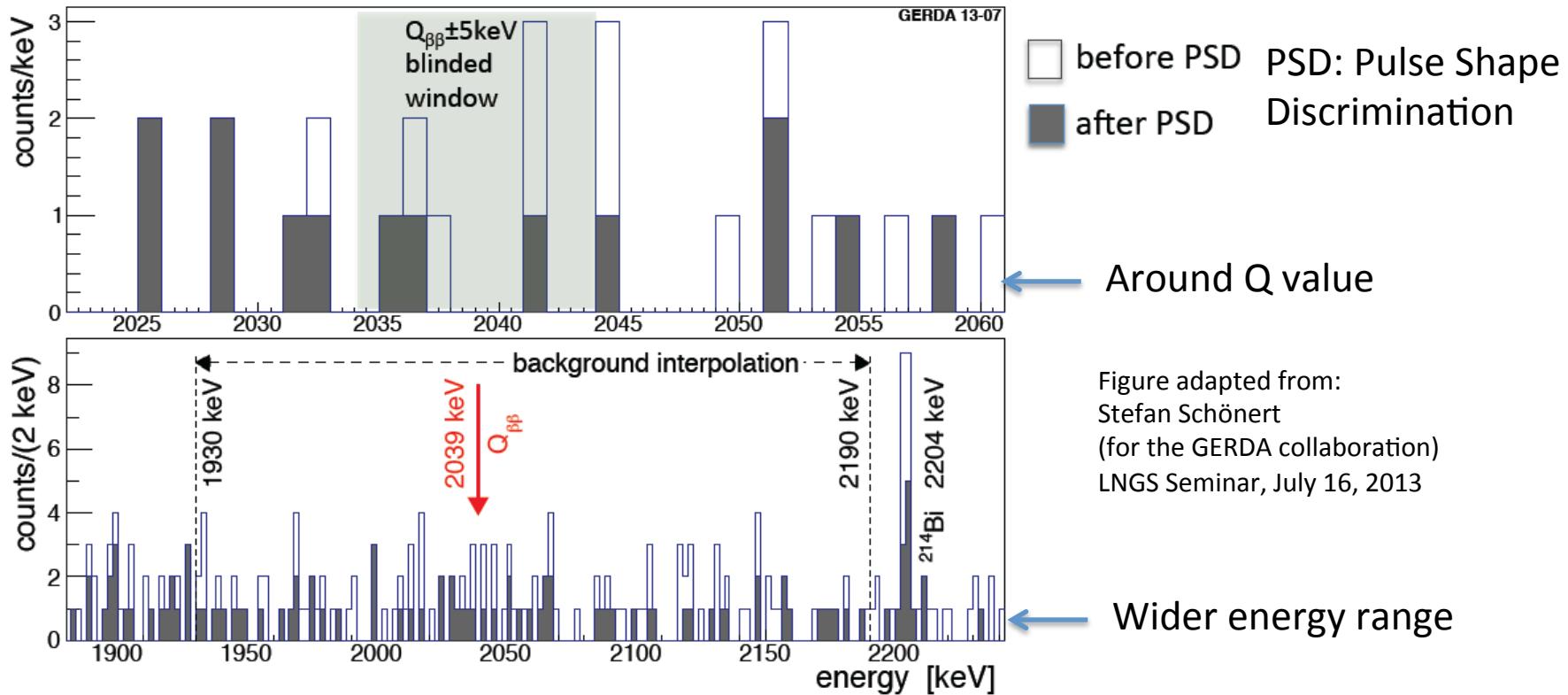


Figure adapted from:
Stefan Schönert
(for the GERDA collaboration)
LNGS Seminar, July 16, 2013

Full data set:

7 event in blinded window
3 event survive PSD cut

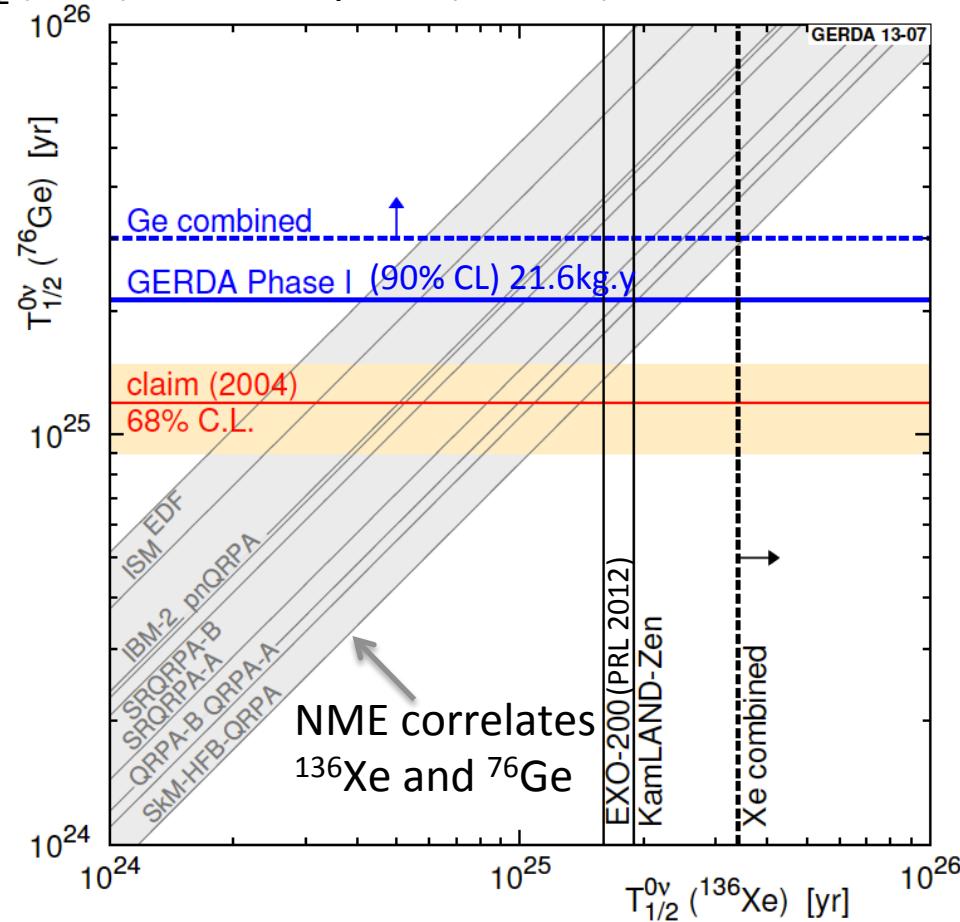
Expect 5.1 background
Expect 2.5 background

No $0\nu\beta\beta$



GERDA phase I results

GERDA, $T_{1/2}^{0\nu}({}^{76}\text{Ge}) > 2.1 \times 10^{25}$ years (90% CL), PRL 111, 122503 (2013)



GERDA puts new limit on neutrinoless double beta decay

Posted on Jul 19, 2013 11:17 am



The GERDA experiment at Gran Sasso. (Courtesy: INFN)

By Hamish Johnston

This stylish chap is looking for an incredibly rare nuclear process called neutrinoless double beta decay. The picture was taken deep under a mountain at Italy's [Gran Sasso National Laboratory](#), which is about 160 km north-west of Rome. He is standing in a cavern containing the [GERDA](#) experiment, which has been searching for the rare decay since 2011.

GERDA hasn't actually detected a decay event, but the collaboration claims to have measured the best value yet of the lower limit on its half-life in germanium-76. They researchers say that it's about 2.1×10^{25} years – or 21 yottayears!

Neutrinoless double beta decay occurs when two neutrons in a nucleus transform into two protons and two electrons. "Neutrinoless" is used to distinguish the process from double beta decay, in which two electron antineutrinos are produced in addition to the protons and electrons. Double beta decay is also extremely rare, having a half-life of about 2×10^{21} years in germanium-76.

Actually seeing neutrinoless double beta decay would provide important information about neutrinos and point to physics beyond the Standard Model. Its observation would imply that neutrinos are Majorana particles, that is they are their own antiparticles. Indeed, the simplest model of the decay process involves the two neutrinos annihilating – as a particle and antiparticle would.

A precise measurement of the half-life would give us the "Majorana neutrino mass". We currently only have upper limits on neutrino masses, as well as information about the ratios of the masses of different flavours of neutrino. Therefore, such a measurement would be a huge breakthrough in neutrino physics and worthy of a Nobel prize.

The existence of Majorana-like neutrinos could point to a solution to one of the most important mysteries of physics: why there is much more matter than antimatter in the Universe.

The GERDA result is also interesting because it casts further doubt on a claim made in 2002 of measuring the half-life. You can read all about that brouhaha in the

Subscribe

News & Features

Topics

Blogs

Videos & Podcasts

Education

Citizen

More Science » Quanta Magazine

6 :: Email :: Print

Search Escalates for Key to Why Matter Exists

Physicists have completed a new round of searches for the answer to why matter dominates antimatter. But the radioactive decay that would solve the puzzle evades them

Oct 23, 2013 | By Natalie Wolchover and Quanta Magazine

From Quanta Magazine (find original story here).

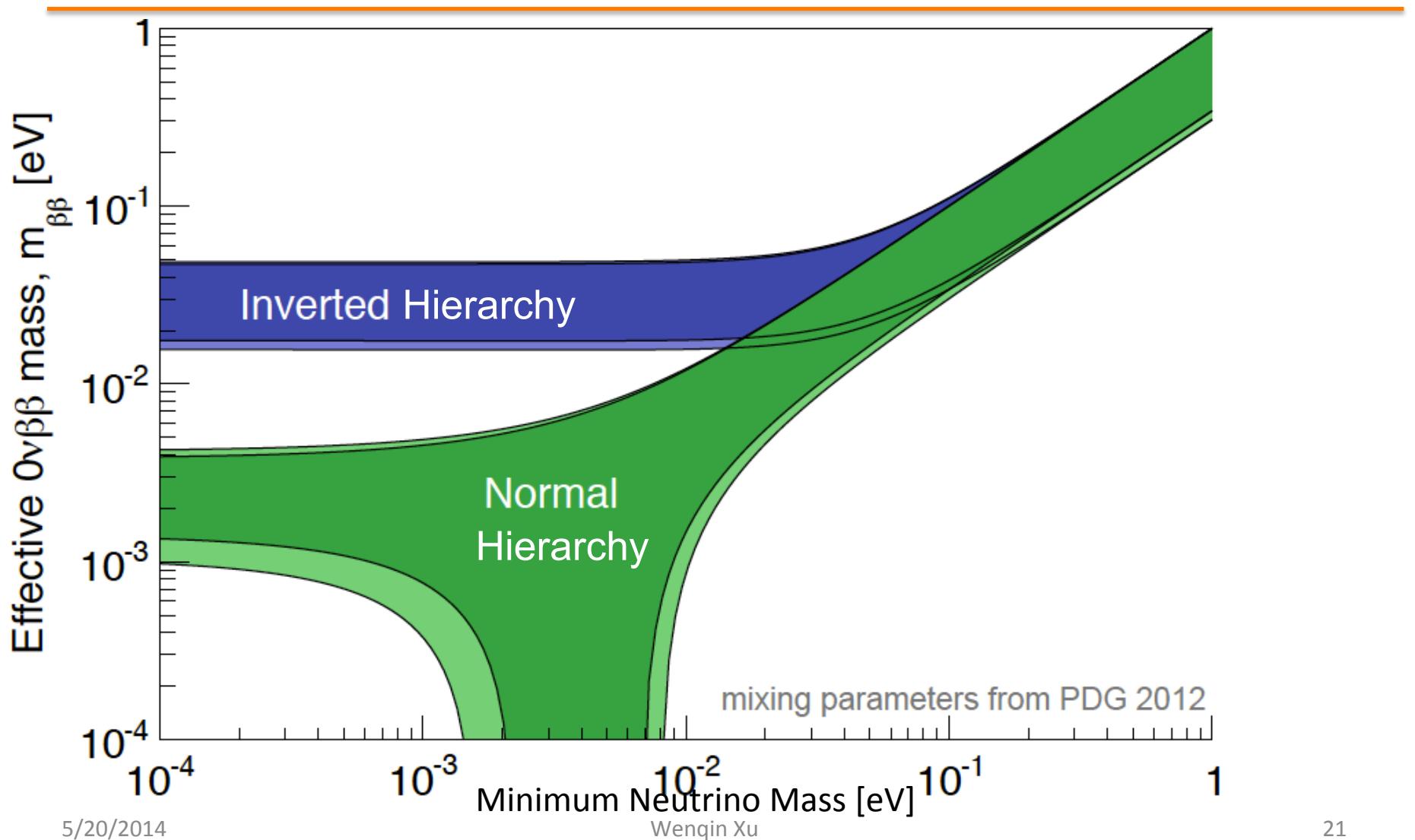
It felt like the Apollo control room seconds before the moon landing. For the approximately 60 physicists crowded into a conference room at the Joint Institute for Nuclear Research in Dubna, Russia, on June 14, this was the moment of truth. After nearly a decade of work, the result of their painstaking search for one of the rarest radioactive decay processes in the universe — if it exists — was about to be revealed.



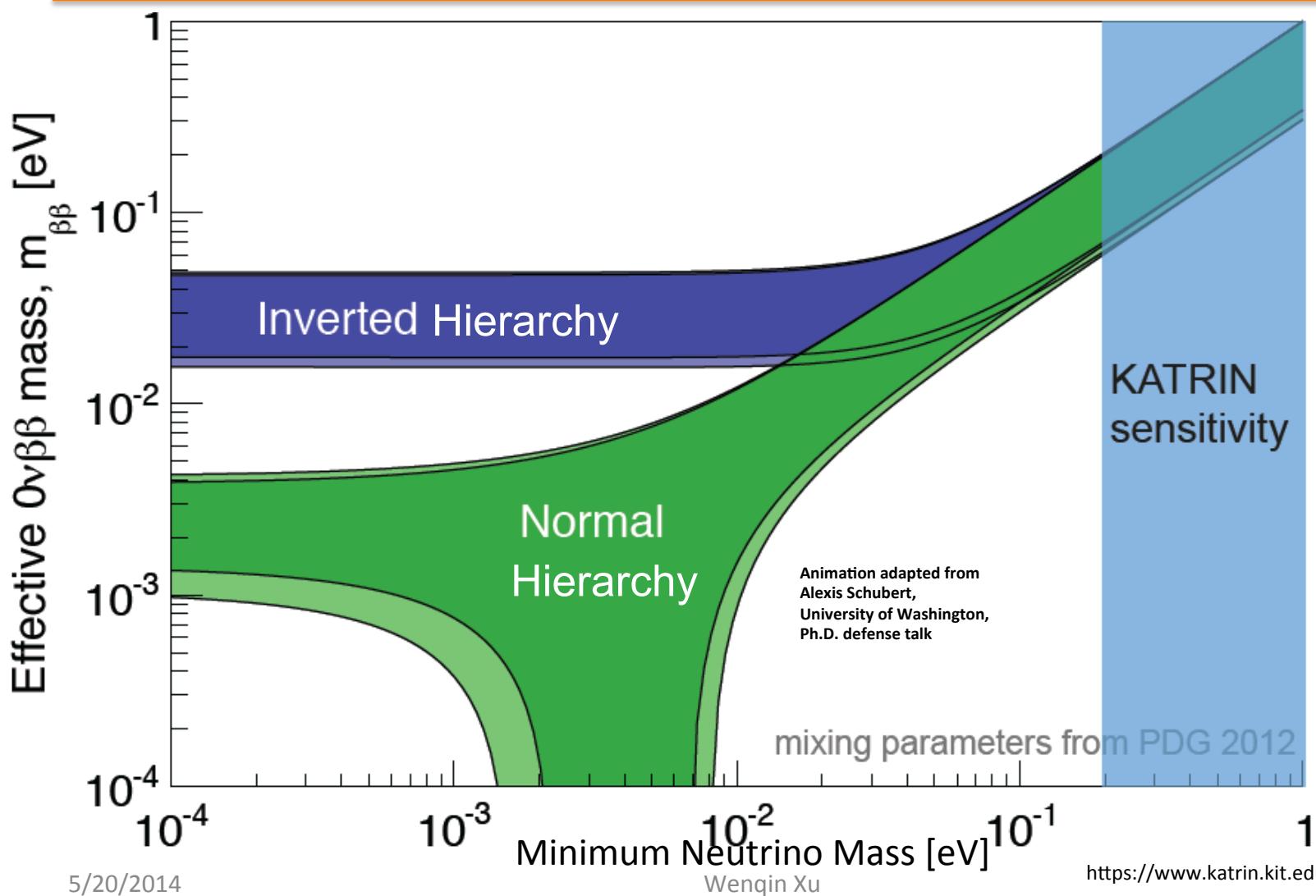
Kai Freund/GERDA collaboration

The hunting grounds were 15 kilograms of pure Germanium crystals kept in extreme isolation deep under a mountain in Italy. Members of the GERmanium Detector Array (GERDA) Collaboration had monitored electrical activity inside the crystals hoping to detect "neutrino-less double beta decay," a spontaneous reshuffling of particles inside the nucleus of a Germanium-76

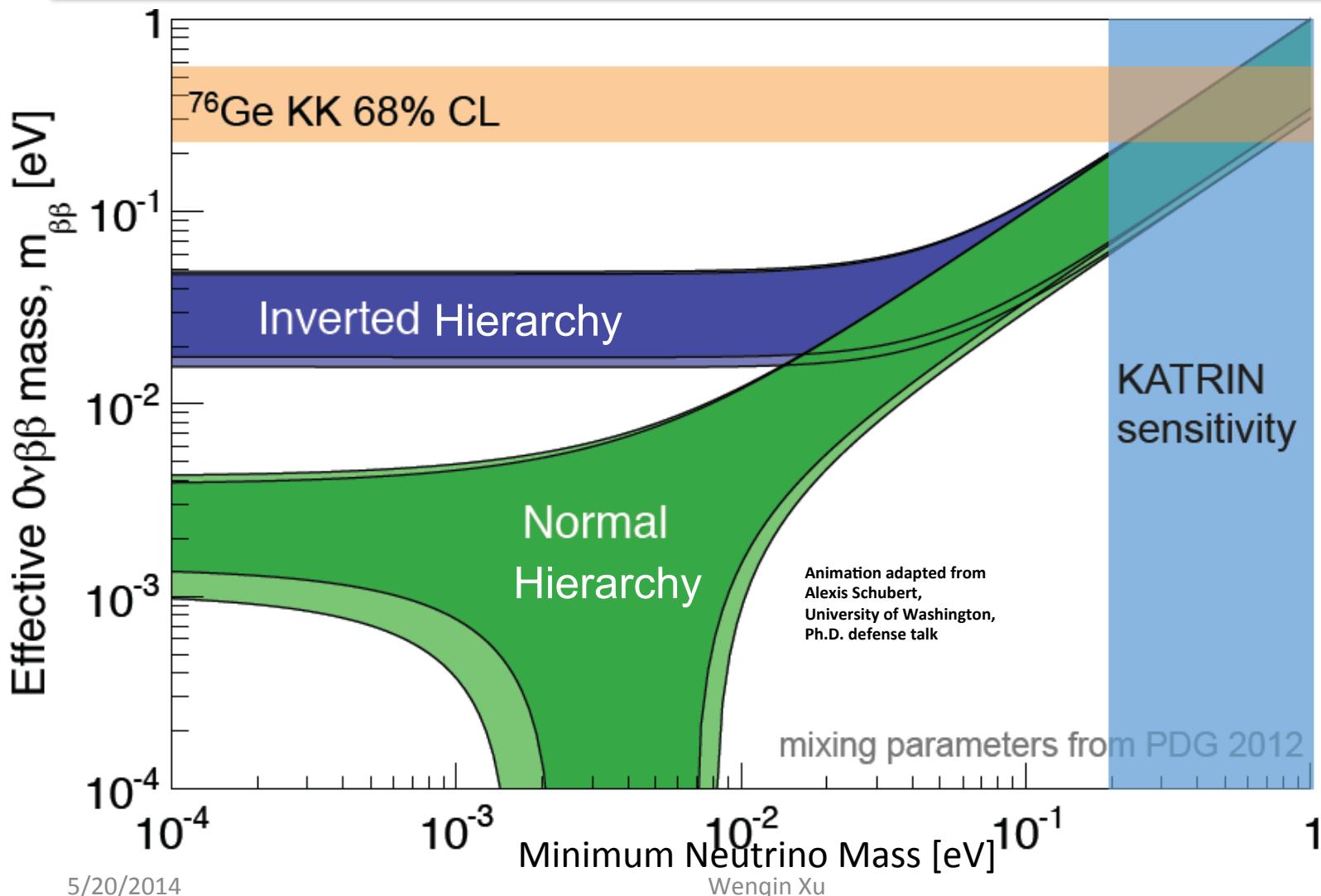
The mass plot



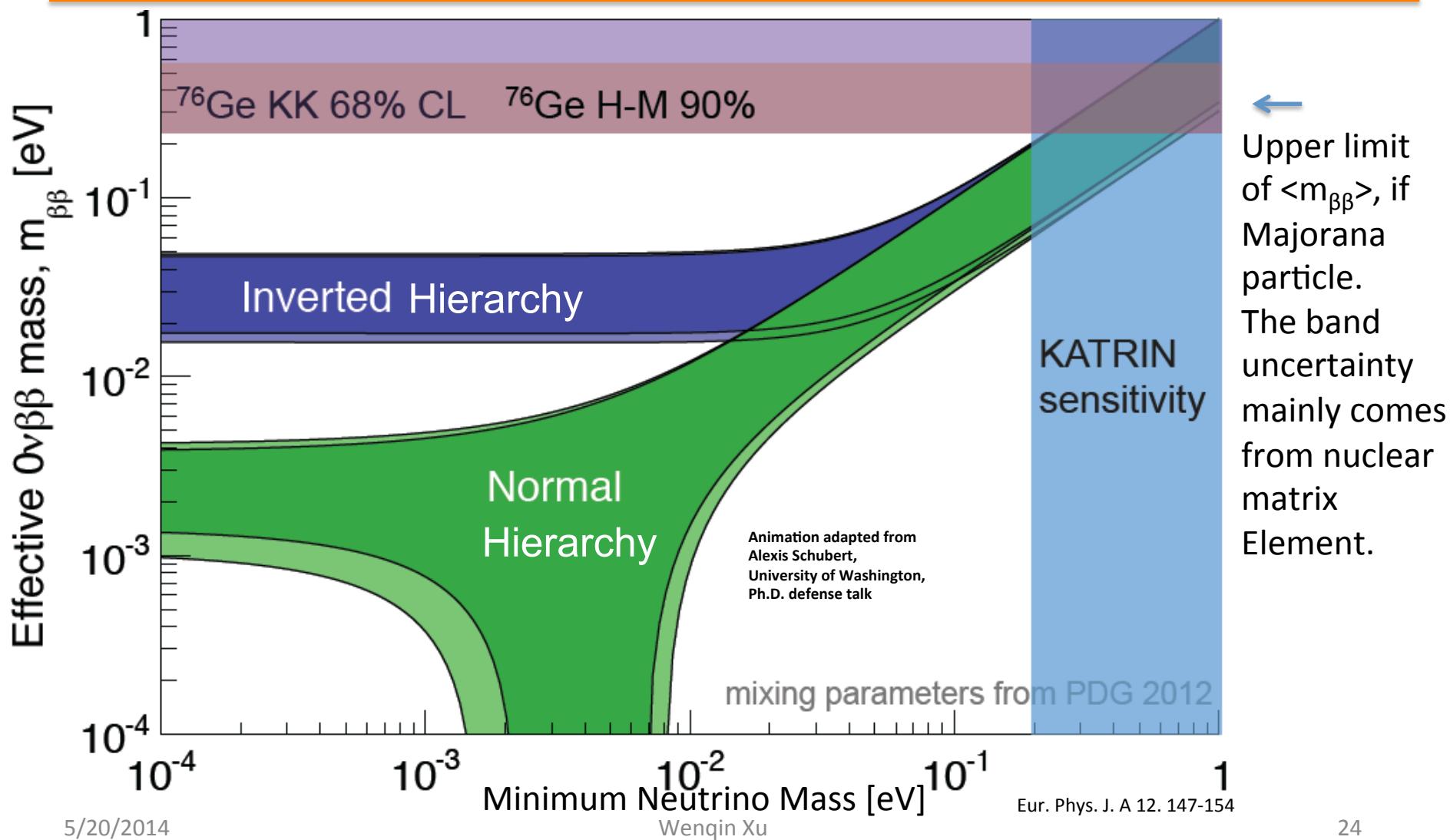
KATRIN sensitivity



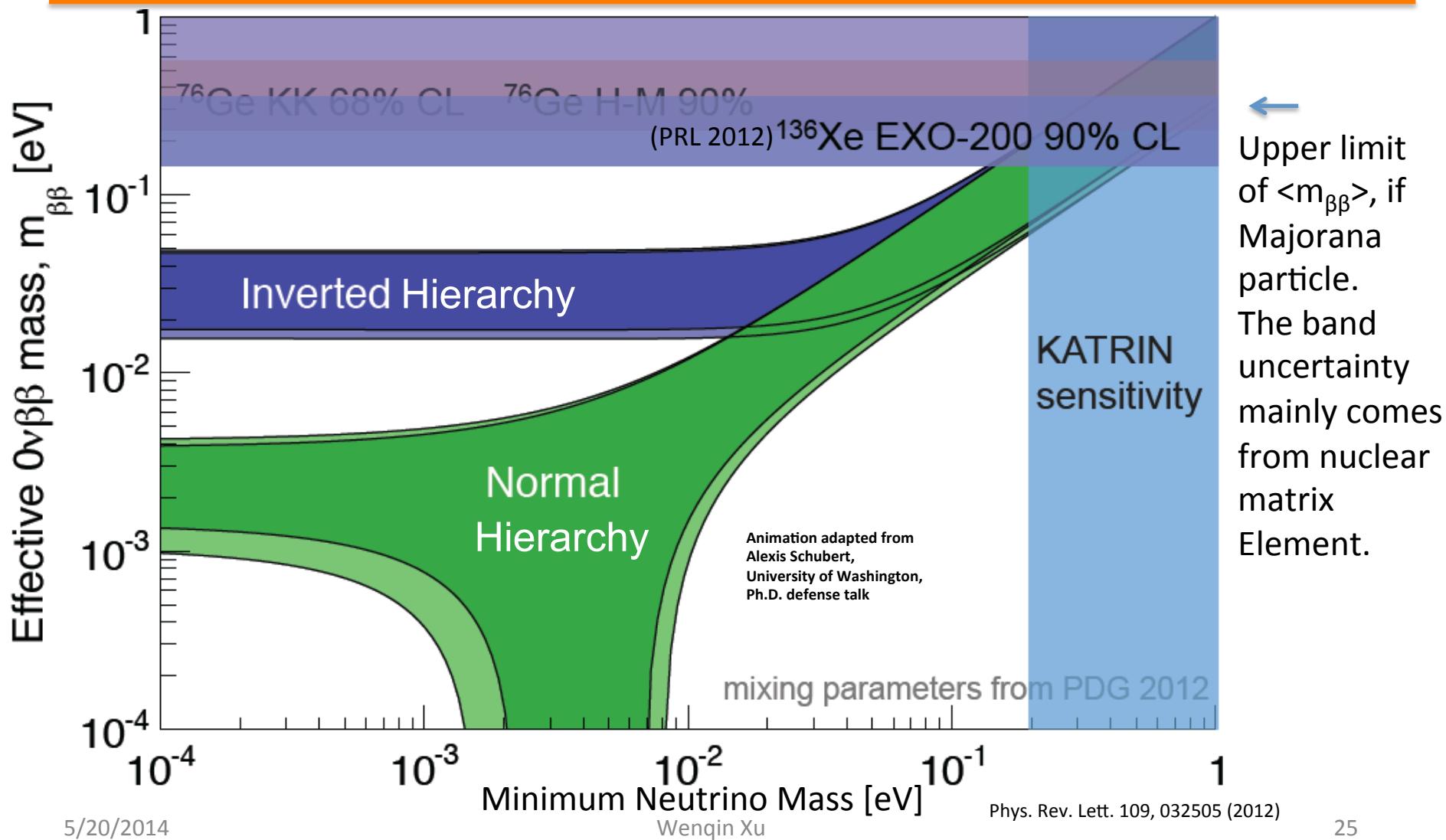
Neutrinoless double beta decay



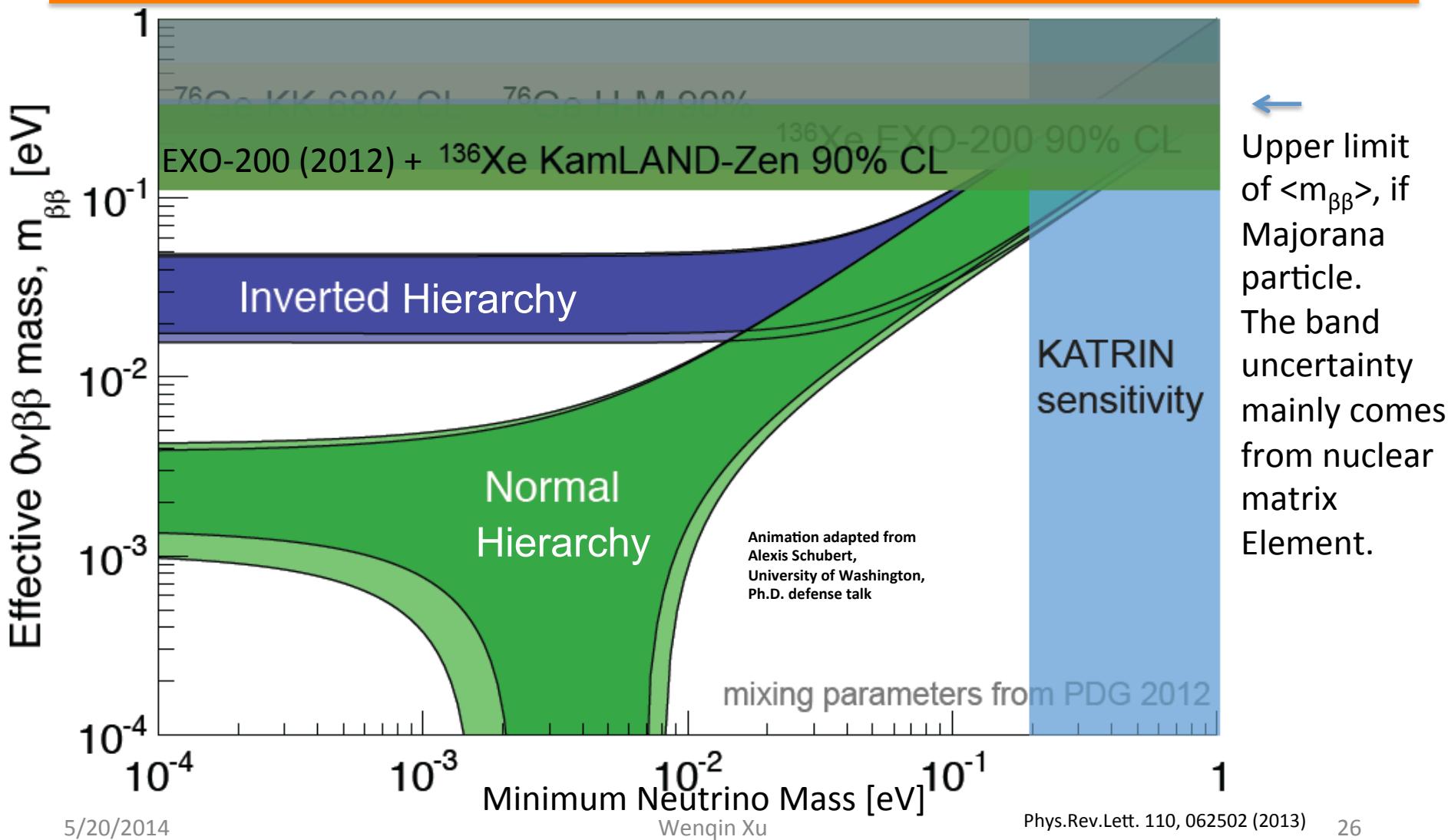
Neutrinoless double beta decay



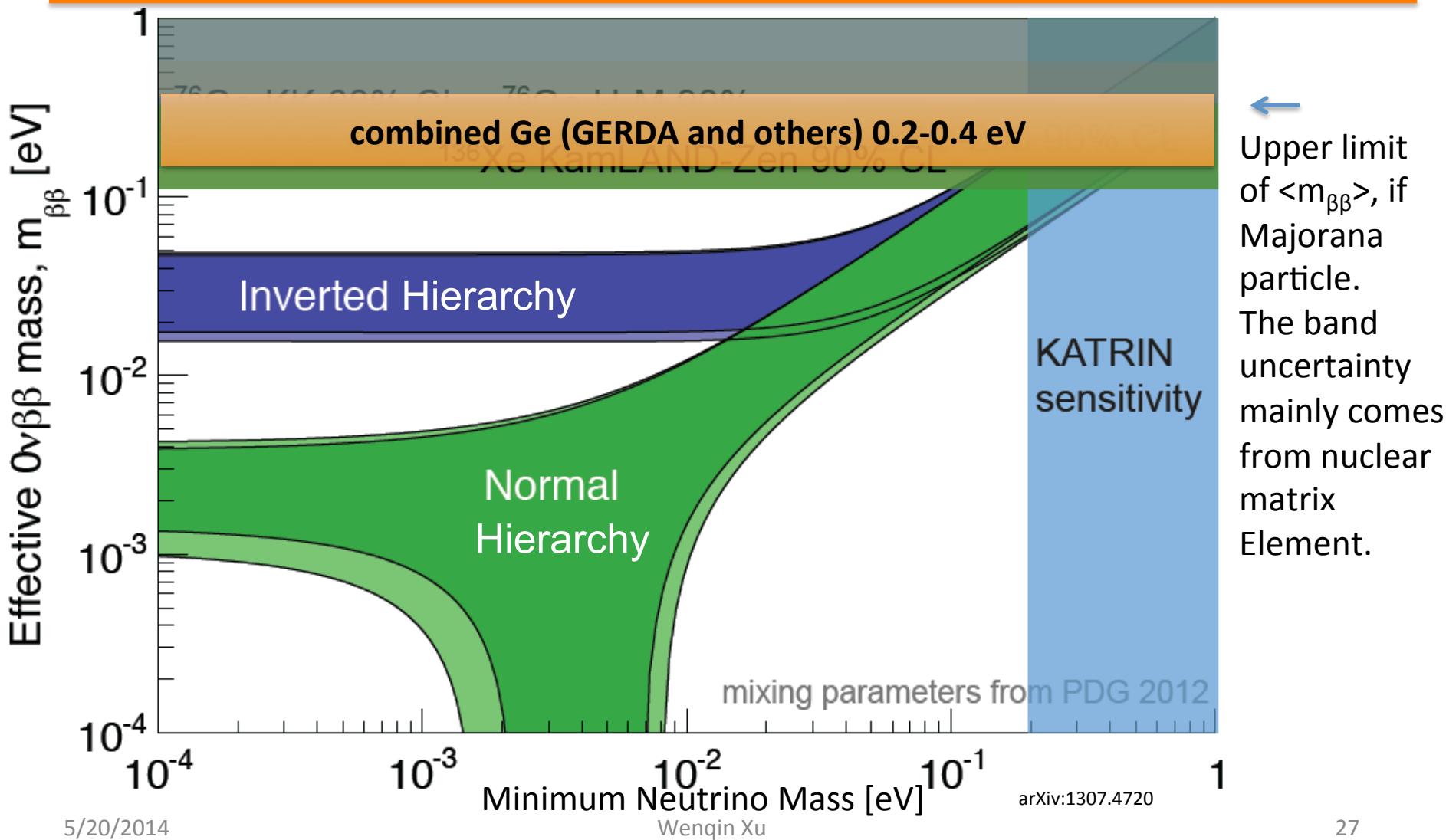
Neutrinoless double beta decay



Neutrinoless double beta decay

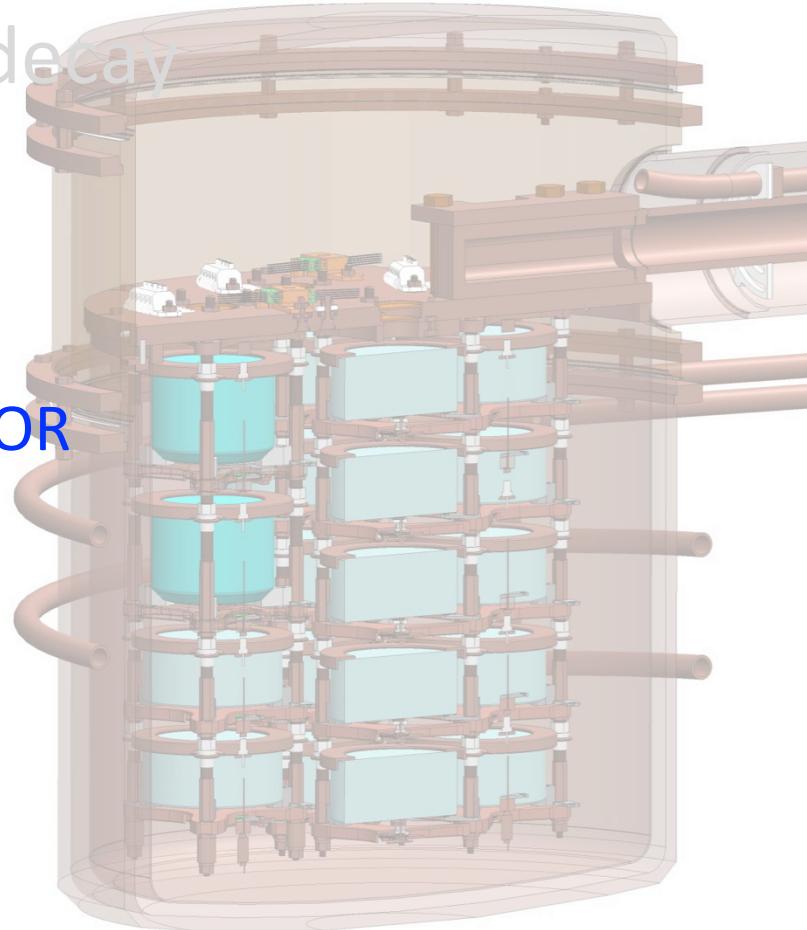


Neutrinoless double beta decay



Outline of the talk

- Neutrinoless double-beta decay
 - the physics
 - the experiments
- The MAJORANA DEMONSTRATOR



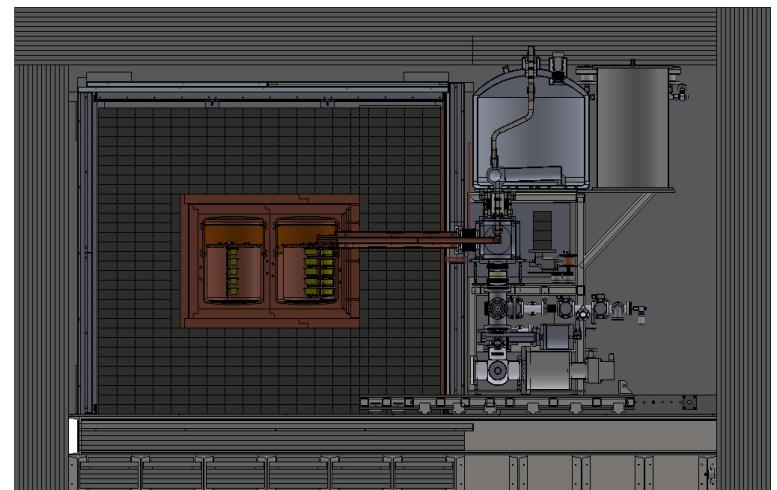
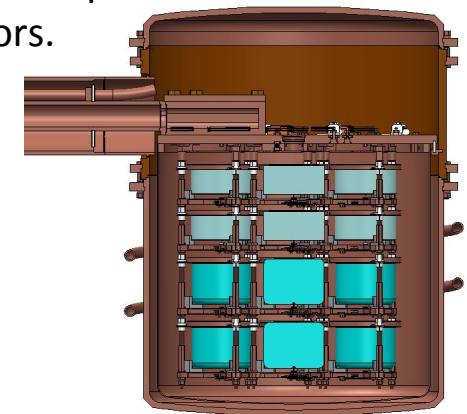


The MAJORANA DEMONSTRATOR

Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

- Goals:**
- Demonstrate backgrounds low enough to justify building a tonne scale experiment.
 - Establish feasibility to construct & field modular arrays of Ge detectors.
 - Test Klapdor-Kleingrothaus claim.
 - Low-energy dark matter (light WIMPs, axions, ...) searches.

- Located underground at 4850' Sanford Underground Research Facility
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
[3 counts/ROI/t/y \(after analysis cuts\)](#)
scales to 1 count/ROI/t/y for a tonne experiment
- 40-kg of Ge detectors
 - 30 kg of 86% enriched ^{76}Ge crystals &
10 kg of $^{\text{nat}}\text{Ge}$
 - Detector Technology: P-type, point-contact.
- 2 independent cryostats
 - ultra-clean, electroformed Cu
 - 20 kg of detectors per cryostat
 - naturally scalable
- Compact Shield
 - low-background passive Cu and Pb
shield with active muon veto

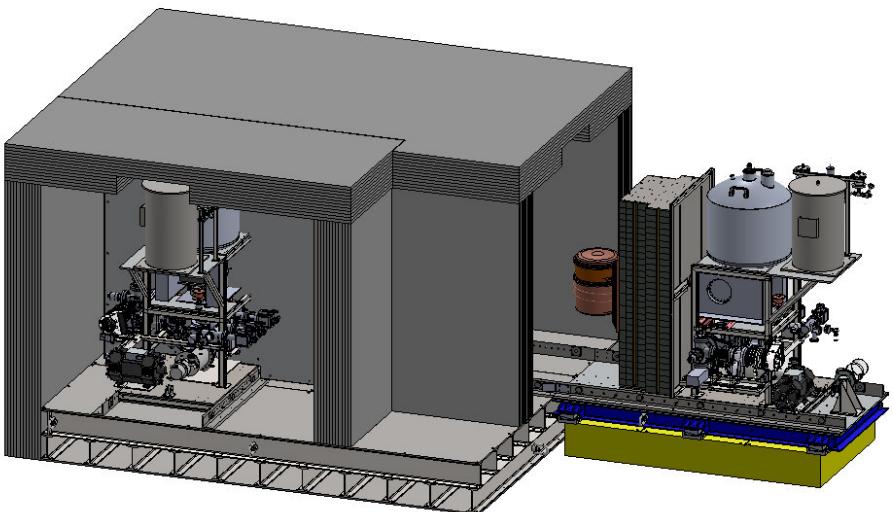
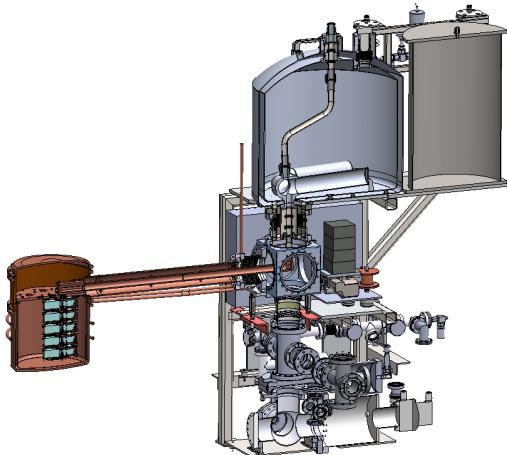




MJD Implementation

- Three Steps

- Prototype Cryostat* (2 strings, ^{nat}Ge)
- Cryostat 1 (3 strings ^{enr}Ge & 4 strings ^{nat}Ge)
- Cryostat 2 (7 strings ^{enr}Ge)

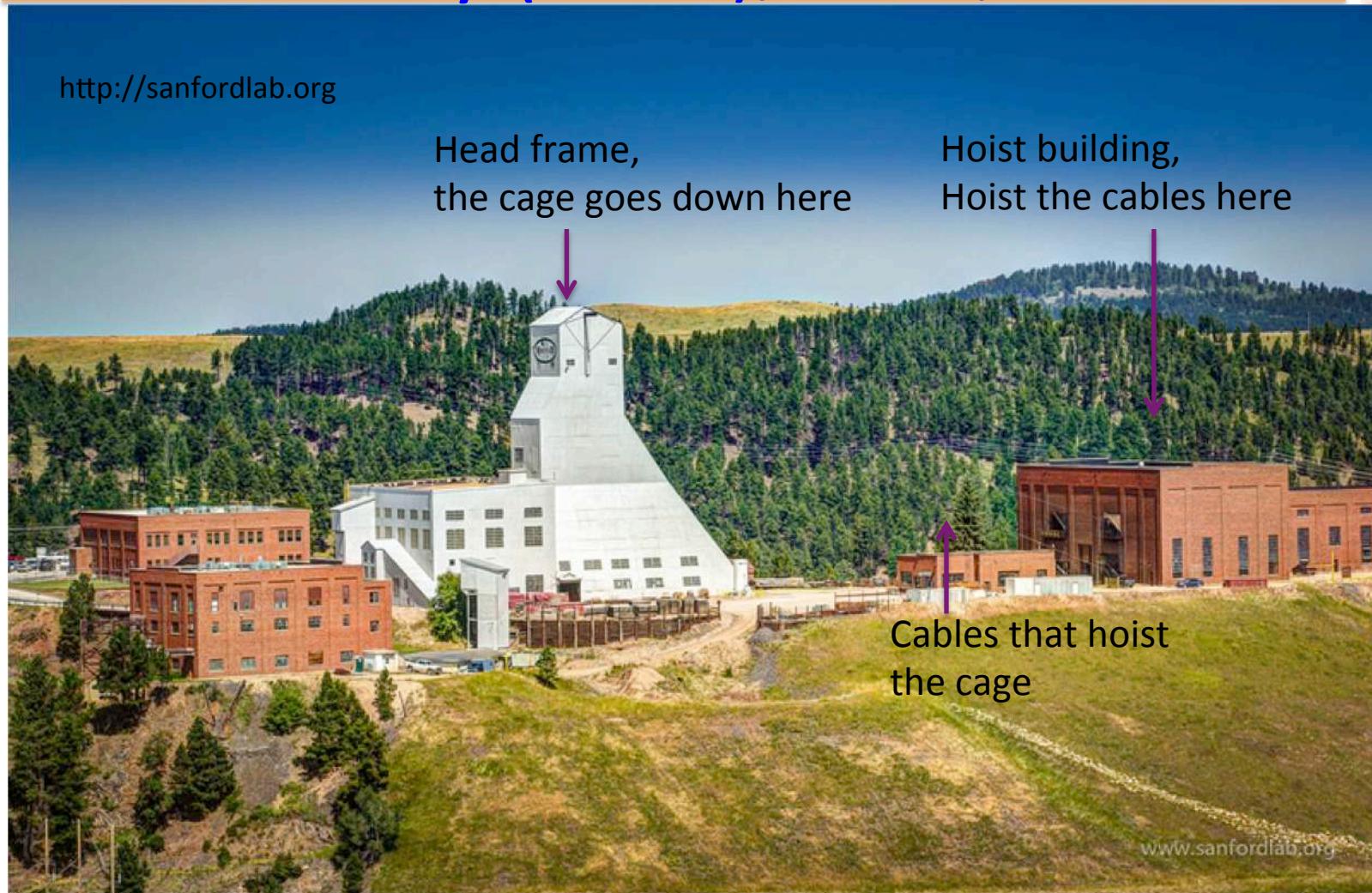


* Same design as Cryos 1 & 2, but fabricated using OFHC Cu (non-electroformed) components.

Sanford Underground Research Facility (SURF), Lead, SD



<http://sanfordlab.org>



Sanford Underground Research Facility (SURF), Lead, SD





SURF, head frame

The deputy
Project manager



Cars

The Spokesperson

Sanford Underground Research Facility (SURF), Lead, SD



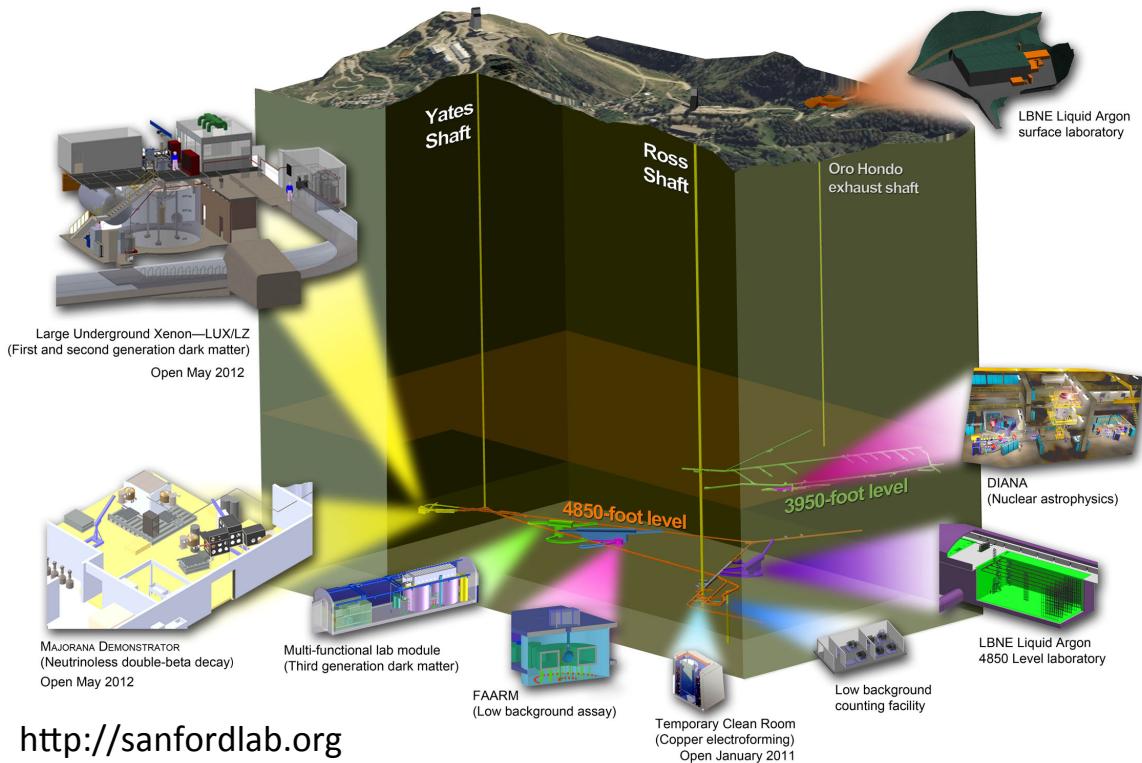
Ray Davis'
Solar Neutrino
Experiment (1967-1985)

2002 Nobel price for
“detecting solar neutrinos”

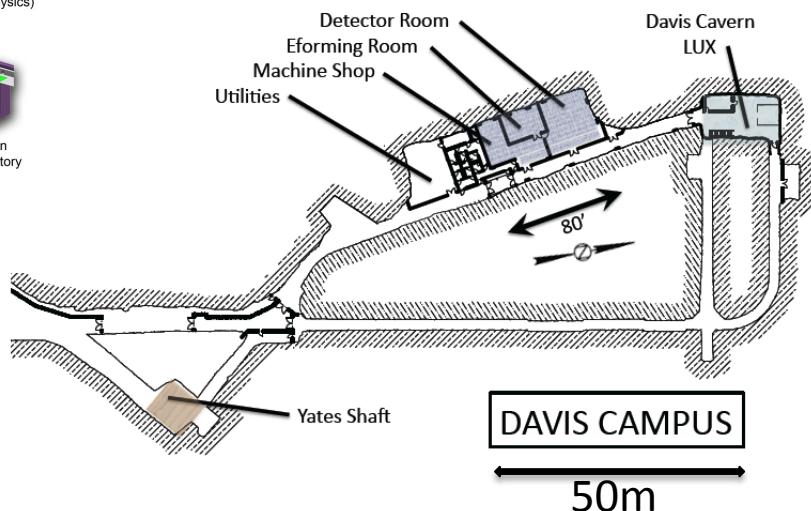
Photo Credit :
Sanford Underground
Research Facility



Sanford Underground Research Facility (SURF), Lead, SD



4850 feet ~ 4260 m.w.e



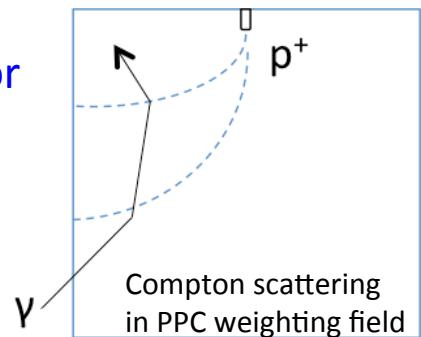
<http://sanfordlab.org>



Point Contact Detector

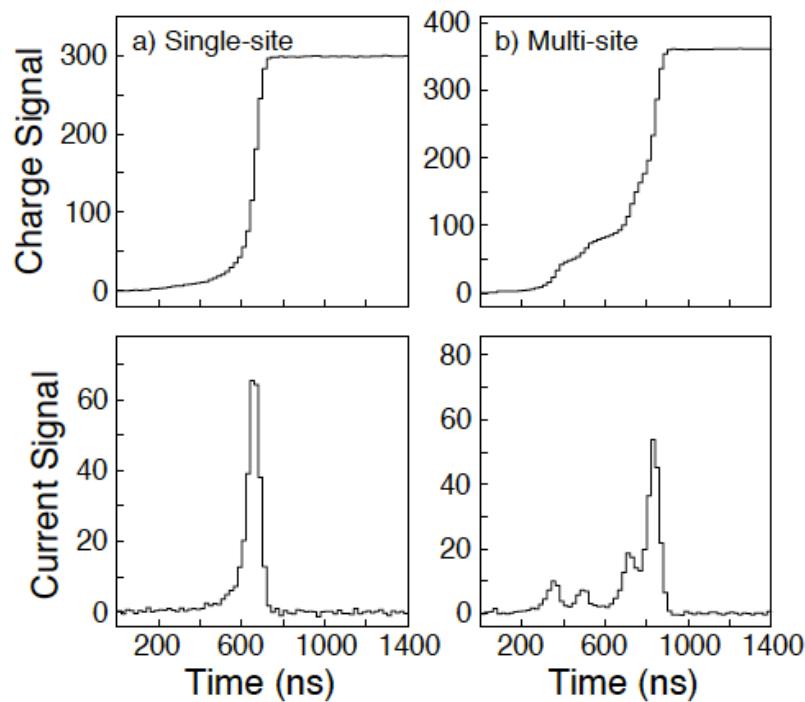


P-type Point Contact Detector
(PPC)



Point Contact Detector:

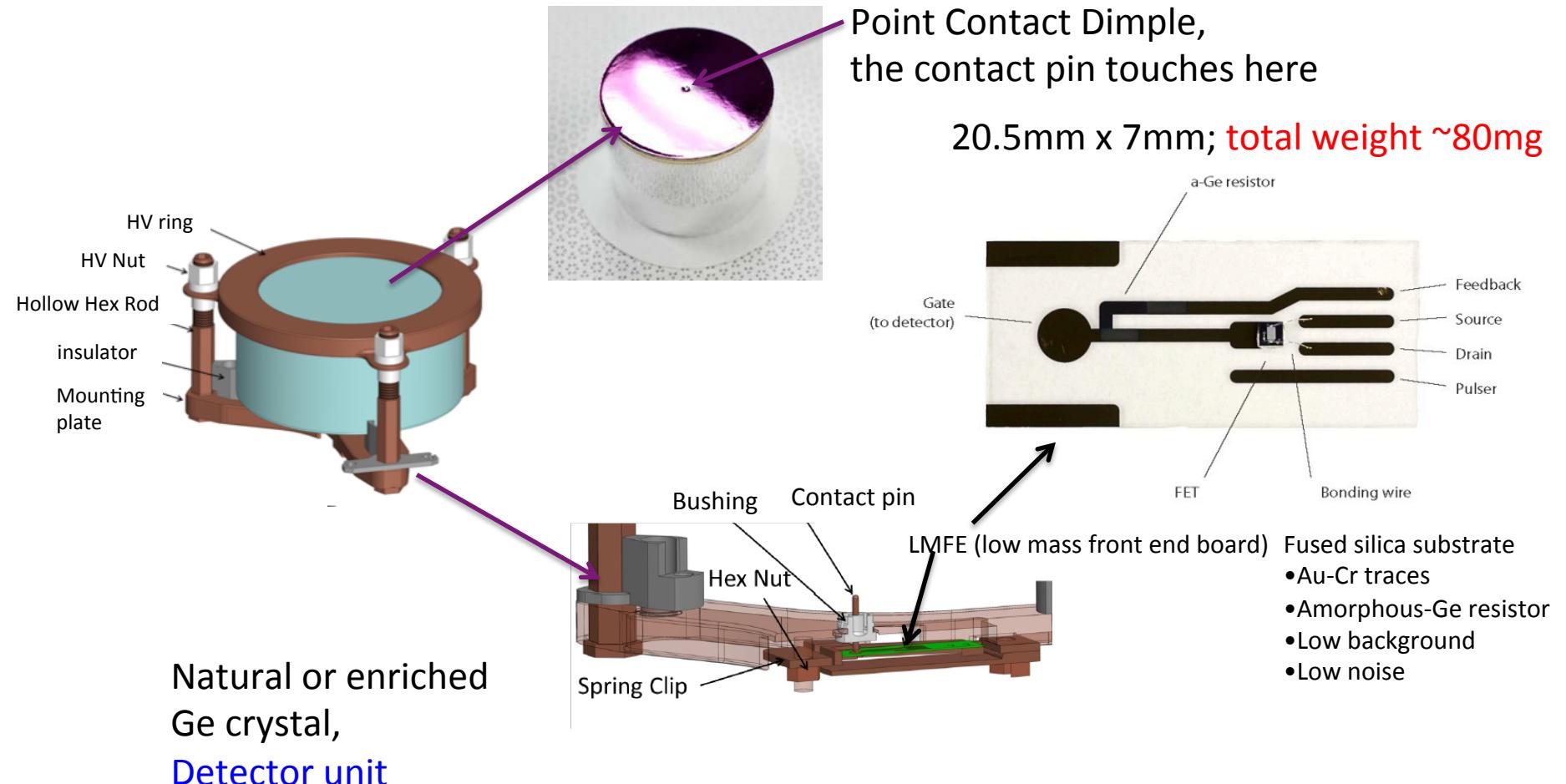
- Relatively low electrical fields
- Larger time spreads for spatially distinct energy depositions
- Crucial in distinguishing multi-site γ background from single-site β signals



Pulse-Shape-Discrimination (PSD)

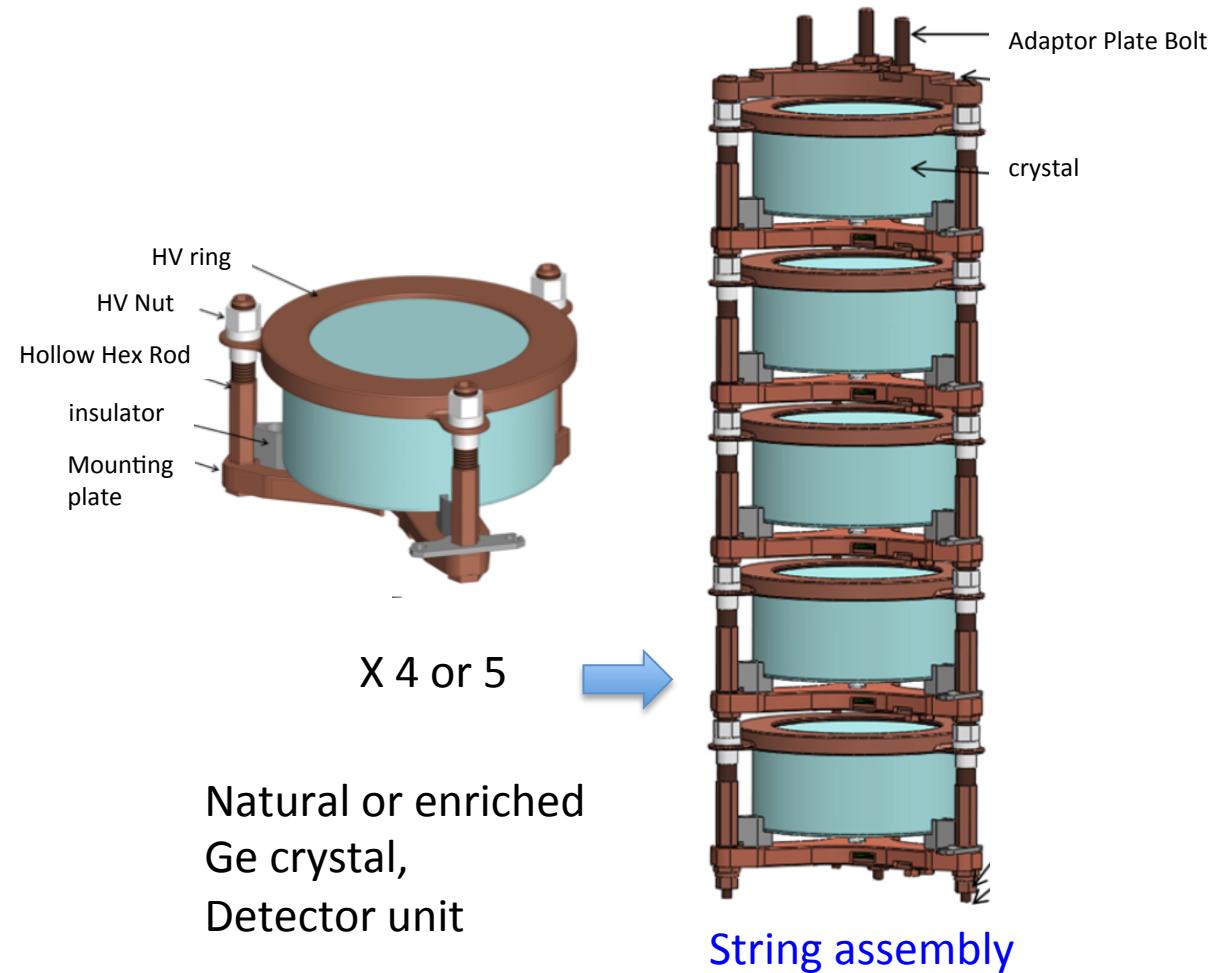


Detector Unit Assemble



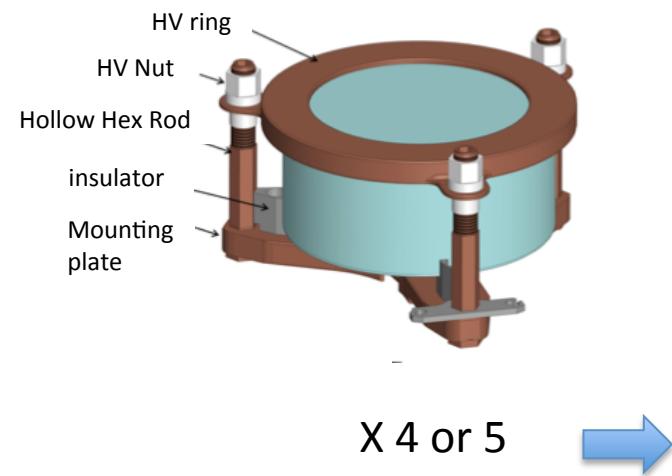


Modular approach



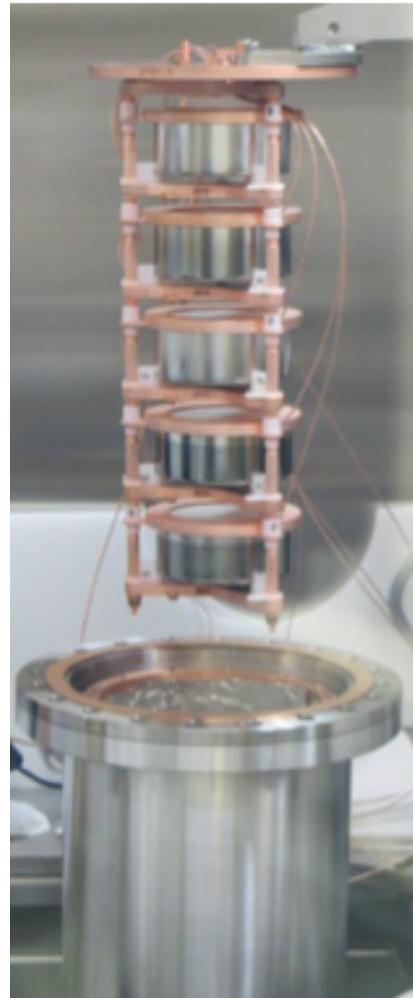


Modular approach



X 4 or 5

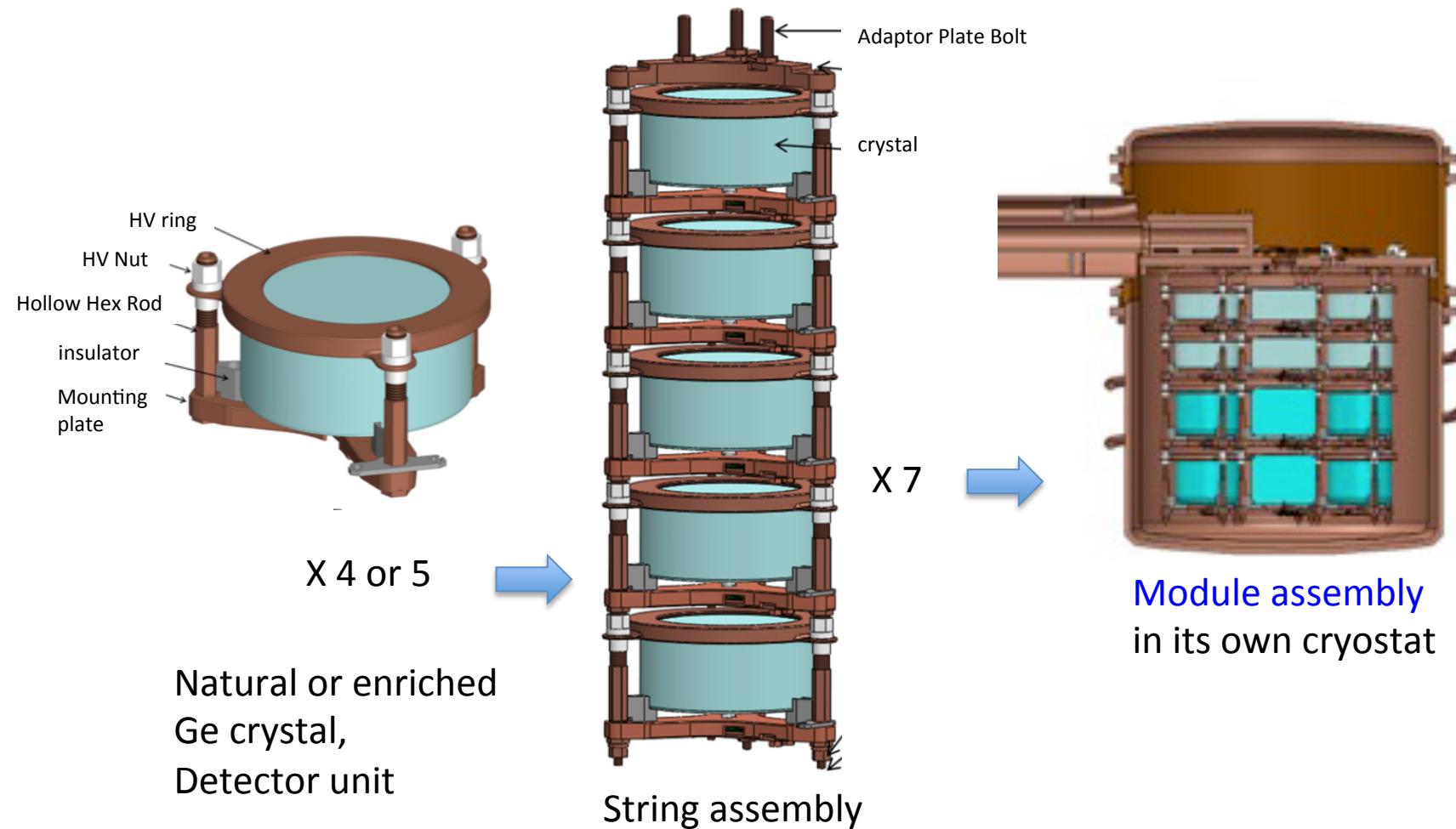
Natural or enriched
Ge crystal,
Detector unit



Our string #1

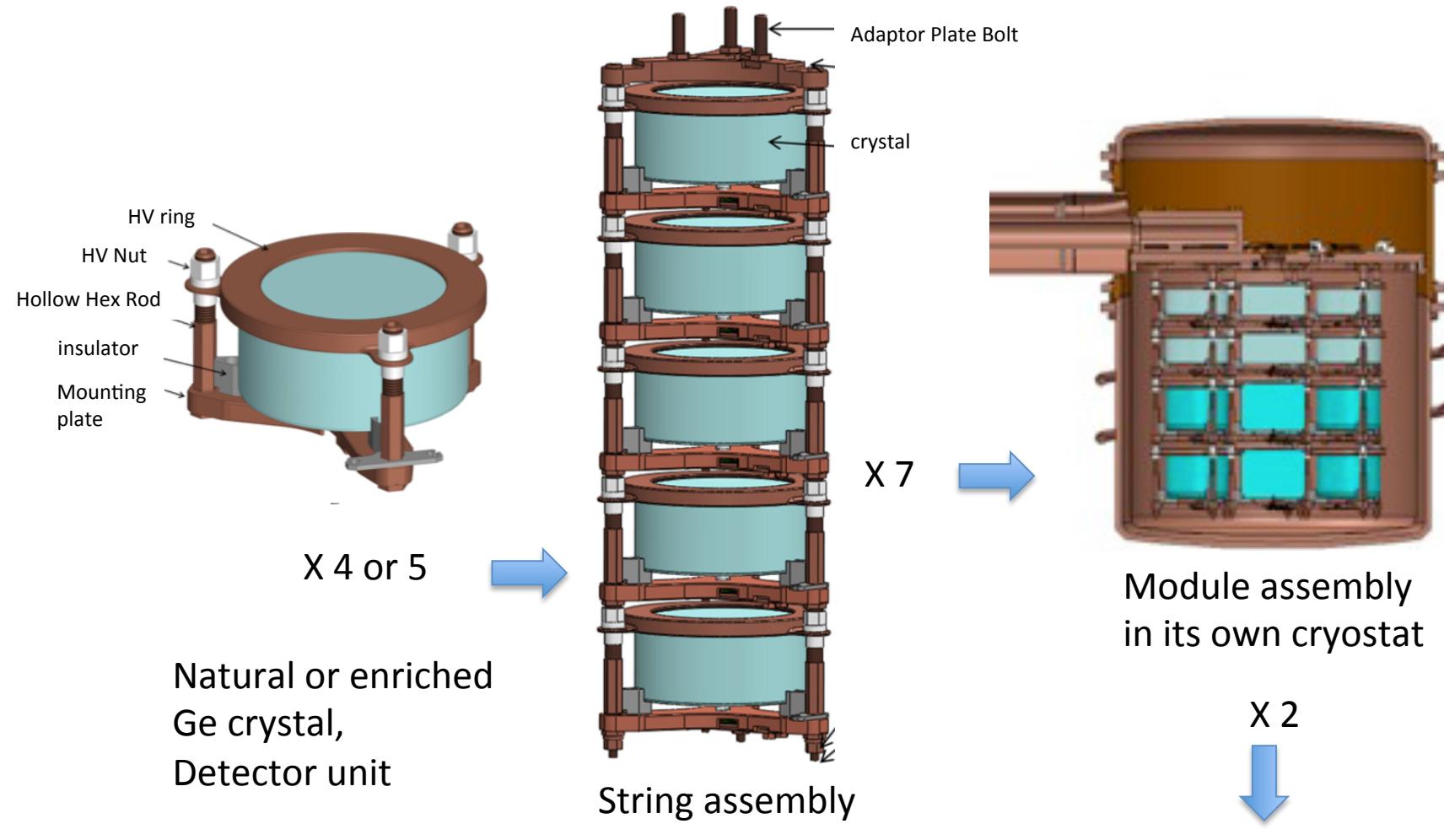


Modular approach



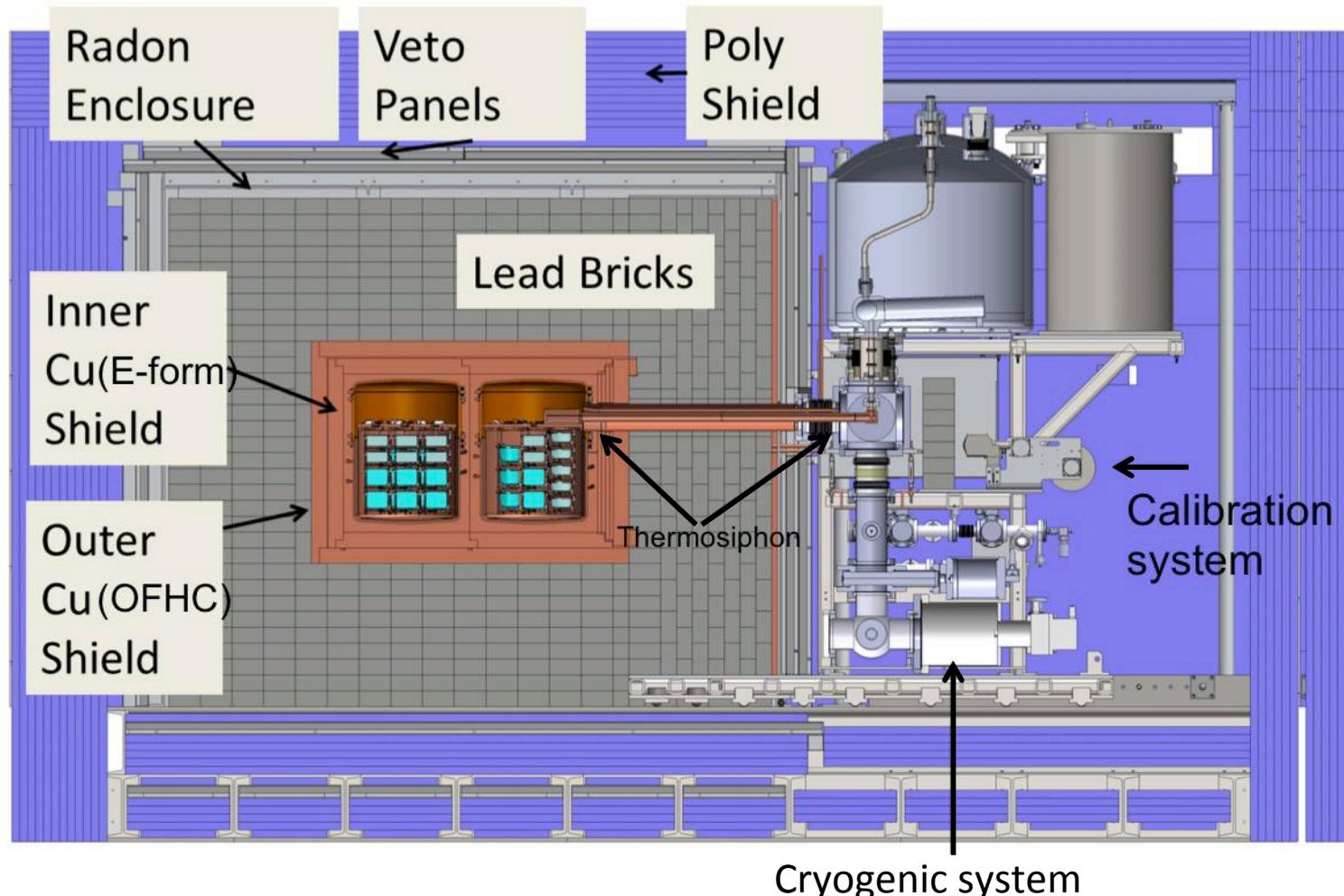


Modular approach





The shielding



The veto panels (scintillating acrylic 2 layers, 2.54cm): **active** shielding.

The others are **passive**:
Poly shield - 30cm;
Radon enclosure - 0.32-0.635cm Al (purged with N₂);
Lead - 45 cm;
Outer Cu - 5 cm;
Inner Cu 4 layers - 1.25 cm each.

Electroformed copper (EFCu)



Assay results for e-form copper ^{232}Th : 0.06 $\mu\text{Bq}/\text{kg}$, ^{238}U : 0.17 $\mu\text{Bq}/\text{kg}$
One order of magnitude better than the cleanest commercial copper (OFHC)



Low background is the key

Natural radioactivity:

- **Pure material** (e.g. EFCu, clean plastic and others)
- **Shielding**
- **Analysis cuts** (PSD, granularity cuts)



Low background is the key

Natural radioactivity:

- **Pure material** (e.g. EFCu, clean plastic and others)
- **Shielding**
- **Analysis cuts** (PSD, granularity cuts)

Cosmogenic:

- **Deep underground** Combined efficiency of two layers of veto panel~99.9%,
Un-vetoed direct muon background<0.03 counts/ROI/t/y.
- **Muon veto**



Low background is the key

Natural radioactivity:

- **Pure material** (e.g. EFCu, clean plastic and others)
- **Shielding**
- **Analysis cuts** (PSD, granularity cuts)

Cosmogenic:

- **Deep underground** Combined efficiency of two layers of veto panel~99.9%,
Un-vetoed direct muon background<0.03 counts/ROI/t/y.
- **Muon veto**
- **Limit surface time of Ge** (shielded shipping and storage)



Low background is the key

Natural radioactivity:

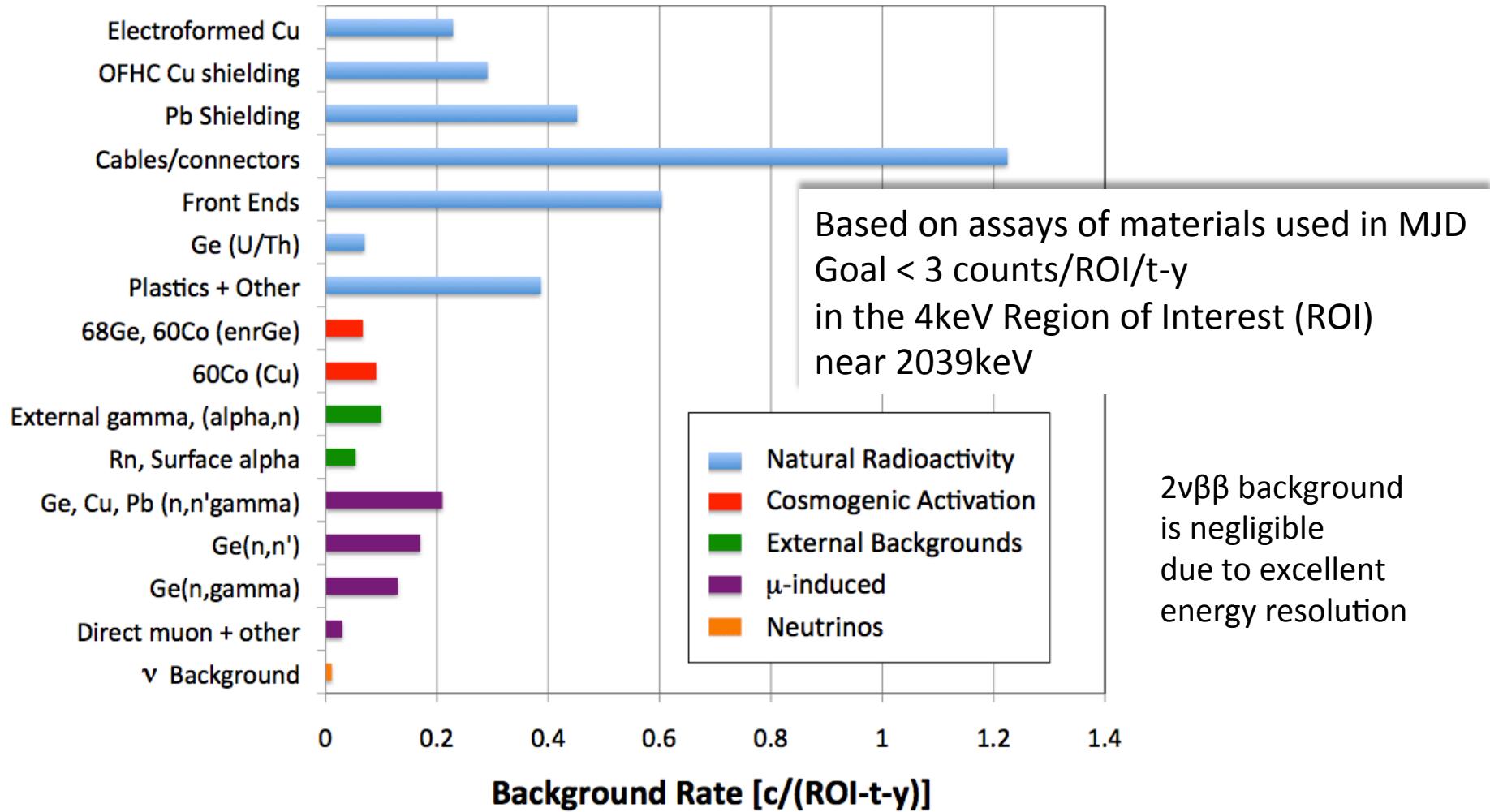
- **Pure material** (e.g. EFCu, clean plastic and others)
- **Shielding**
- **Analysis cuts** (PSD, granularity cuts)

Cosmogenic:

- **Deep underground** Combined efficiency of two layers of veto panel~99.9%,
Un-vetoed direct muon background<0.03 counts/ROI/t/y.
- **Muon veto**
- **Limit surface time of Ge** (shielded shipping and storage)
- **E-form Cu underground**



DEMONSTRATOR background budget



Simulated Background near $Q_{\beta\beta}$ after all cuts



Simulated spectra, 60 kg yrs, detector resolution + all cuts applied

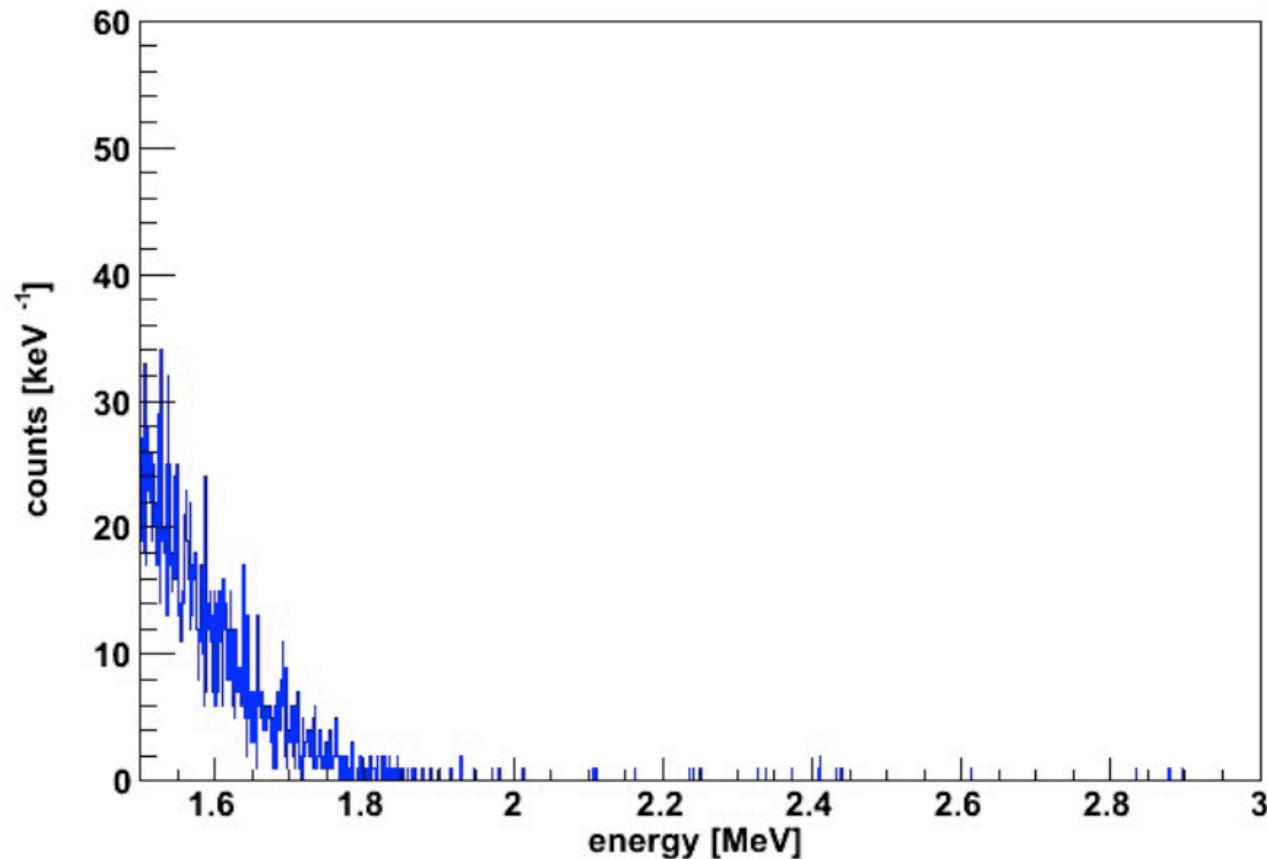


Figure adapted from
J.F.Wilkerson,
DOE ONP Comparative Review
June 25, 2013

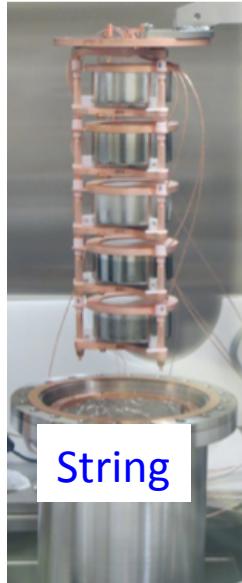


DEMONSTRATOR Status

Clean Room



Shields

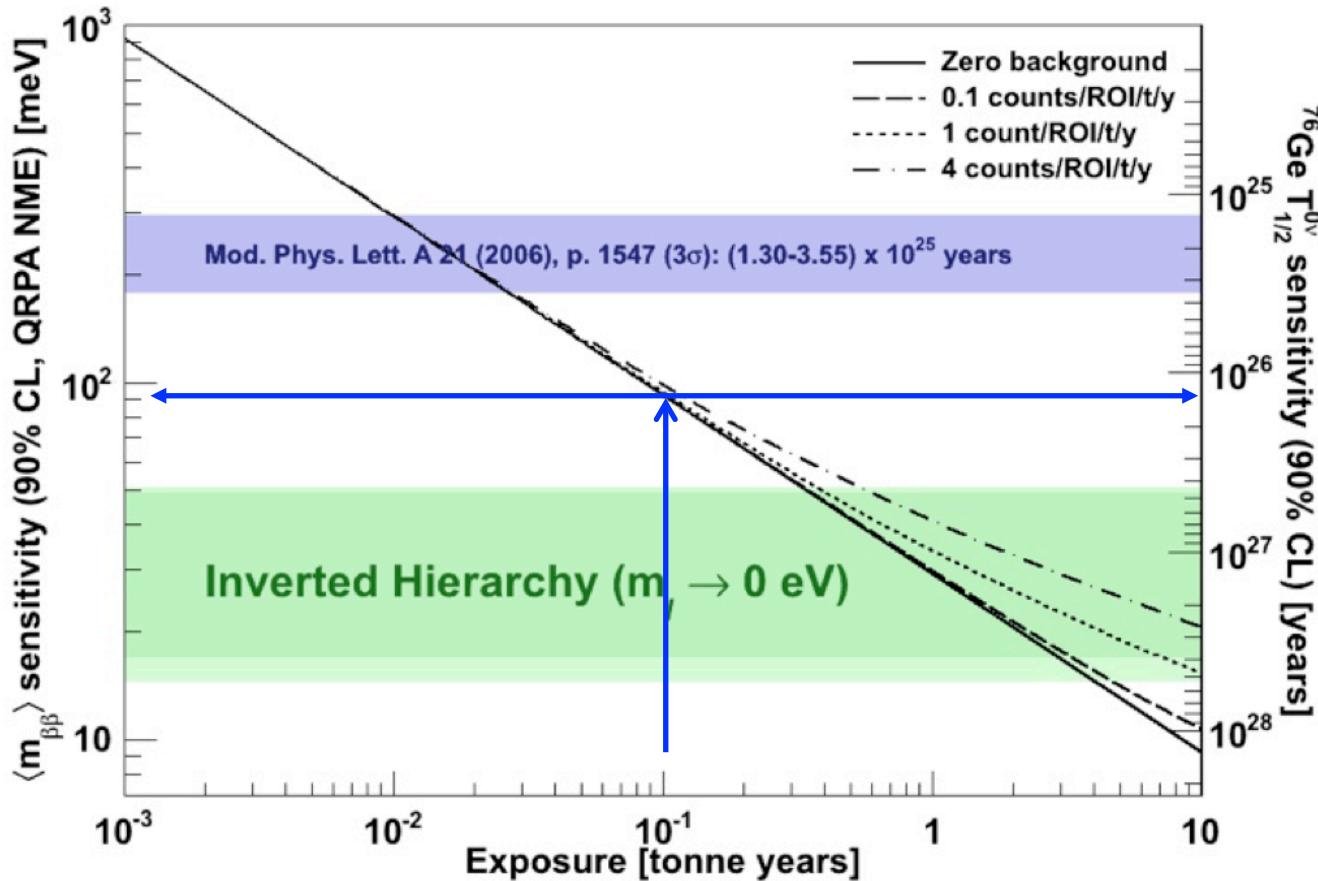


String

- ✓ Infrastructure and cleanliness established
- ✓ Assayed all materials
- ✓ 75% required e-form copper produced
- ✓ 42.5 kg of 86% enriched 76Ge procured, refined to electronic grade with a 98% yield
- ✓ Accepted 30 enriched Ge detectors, 27 kg in total
- ✓ Built two strings of natural Ge detectors
- ✓ Fabricated prototype cryostat and most of cryo 1
- ✓ Built the associated vacuum system
- ✓ Shield construction in progress
- ✓ Slow Control and DAQ in use



DEMONSTRATOR schedule



Prototype Cryostat:
Began Commissioning
Nov 2013

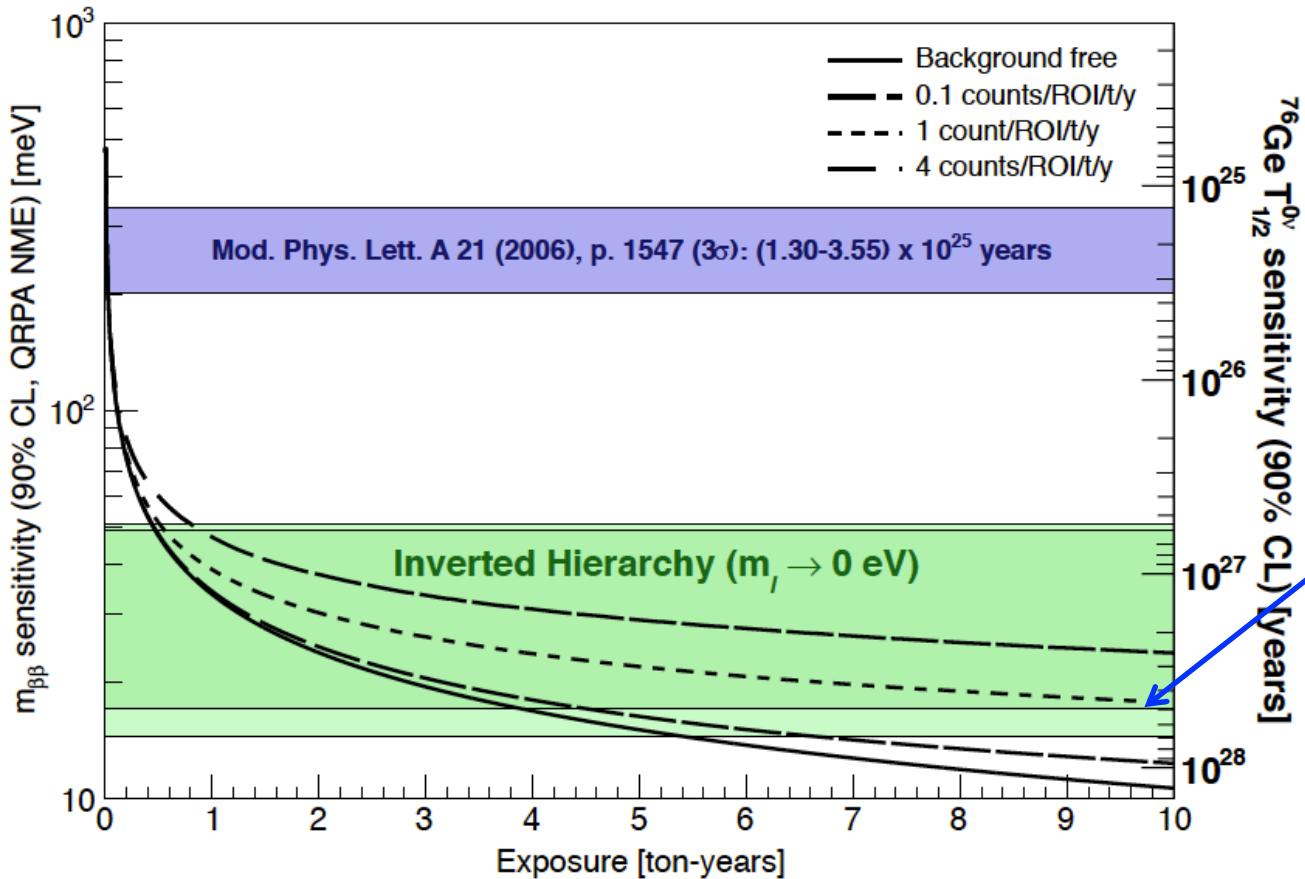
Cryostat 1: Jul. 2014

Cryostat 2: Jul. 2015

Run for 3 years,
exposure~100kg*y.
Sensitive to
 $T \sim 10^{26}$ years



Future Tonne scale sensitivity

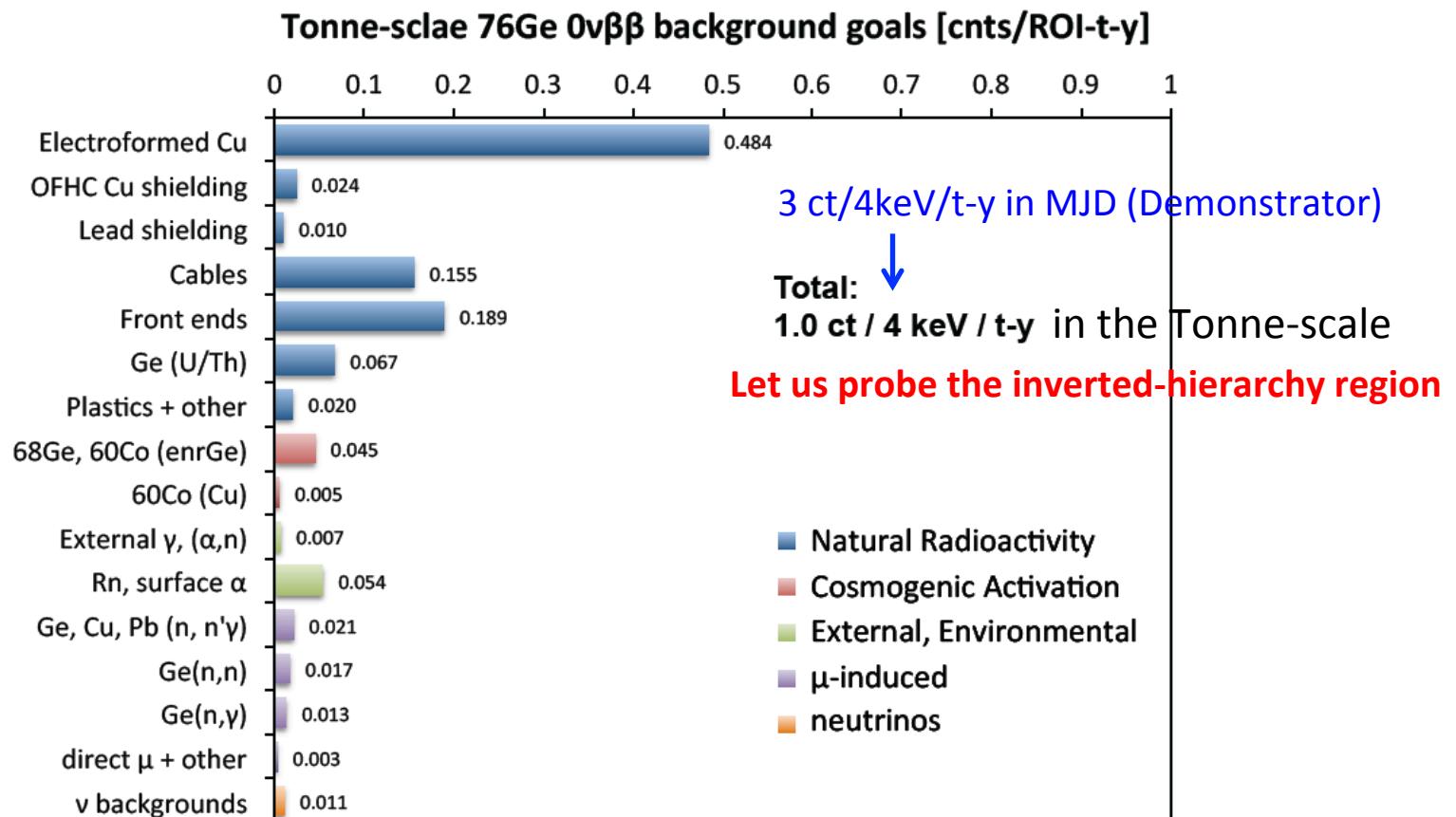


Aim for background
< 1count/ROI/t/y to
probe the entire
inverted-hierarchy region
in a practical time period

Background Projection for Tonne-scale



Scaling from MJD projects



The MAJORANA Collaboration



Black Hills State University, Spearfish, SD

Kara Keeter

Duke University, Durham, North Carolina , and TUNL

Matthew Busch, James Esterline, Gary Swift, Werner Tornow

Institute for Theoretical and Experimental Physics, Moscow, Russia

Alexander Barabash, Sergey Konovalov, Vladimir Yumatov

Joint Institute for Nuclear Research, Dubna, Russia

Viktor Brudanin, Slava Egorov, K. Gusev,
Oleg Kochetov, M. Shirchenko, V. Timkin, E. Yakushev

*Lawrence Berkeley National Laboratory, Berkeley, California and
the University of California - Berkeley*

Nicolas Abgrall, Mark Amman, Paul Barton, Yuen-Dat Chan, Alex Hegai,
Paul Luke, Susanne Mertens, Alan Poon, Kai Vetter, Harold Yaver

Los Alamos National Laboratory, Los Alamos, New Mexico

Melissa Boswell, Steven Elliott, Johnny Goett, Keith Rielage, Larry
Rodriguez, Michael Ronquest, Harry Salazar, Wenqin Xu

North Carolina State University, Raleigh, North Carolina and TUNL

Dustin Combs, Lance Leviner, David G. Phillips II, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee

Fred Bertrand, Kathy Carney, Alfredo Galindo-Uribarri,
Matthew P. Green, David Radford, Elisa Romero-Romero,
Robert Varner, Brandon White, Timothy Williams, Chang-Hong Yu

Osaka University, Osaka, Japan

Hiroyasu Ejiri, Ryuta Hazama, Masaharu Nomachi, Shima Tatsuji

Pacific Northwest National Laboratory, Richland, Washington

Estanislao Aguayo, Jim Fast, Eric Hoppe, Richard T. Kouzes, Brian LaFerriere, John Orrell,
Nicole Overman, Doug Reid, Aleksandr Soin

Shanghai Jiaotong University, Shanghai, China

James Loach

South Dakota School of Mines and Technology, Rapid City, South Dakota

Adam Caldwell, Cabot-Ann Christofferson, Stanley Howard,
Anne-Marie Suriano, Jared Thompson

Tennessee Tech University, Cookeville, Tennessee

Mary Kidd

University of Alberta, Edmonton, Alberta

Aksel Hallin

University of North Carolina, Chapel Hill, North Carolina and TUNL

Florian Fraenkle, Graham K. Giovanetti, Reyco Henning, Mark Howe,
Jacqueline MacMullin, Benjamin Shanks, Christopher O'Shaughnessy,
Kris Vorren, John F. Wilkerson

University of South Carolina, Columbia, South Carolina

Frank Avignone, Vince Guiseppe, Clint Wiseman

University of South Dakota, Vermillion, South Dakota

Dana Byram, Ryan Martin, Nathan Snyder

University of Tennessee, Knoxville, Tennessee

Yuri Efremenko, Sergey Vasilyev

University of Washington, Seattle, Washington

Tom Burritt, Clara Cuesta, Jason Detwiler, Peter J. Doe, Julieta Gruszko, Greg Harper,
Jonathan Leon, David Peterson, R. G. Hamish Robertson, Alexis Schubert, Tim





The END

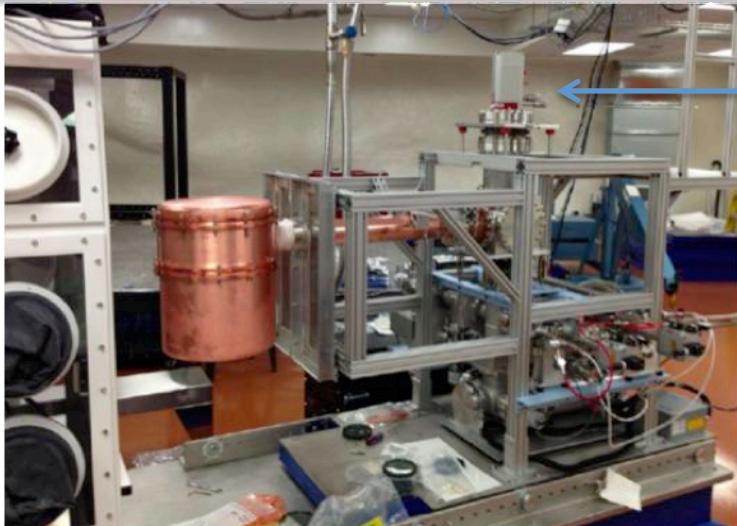
THANK YOU!

backup



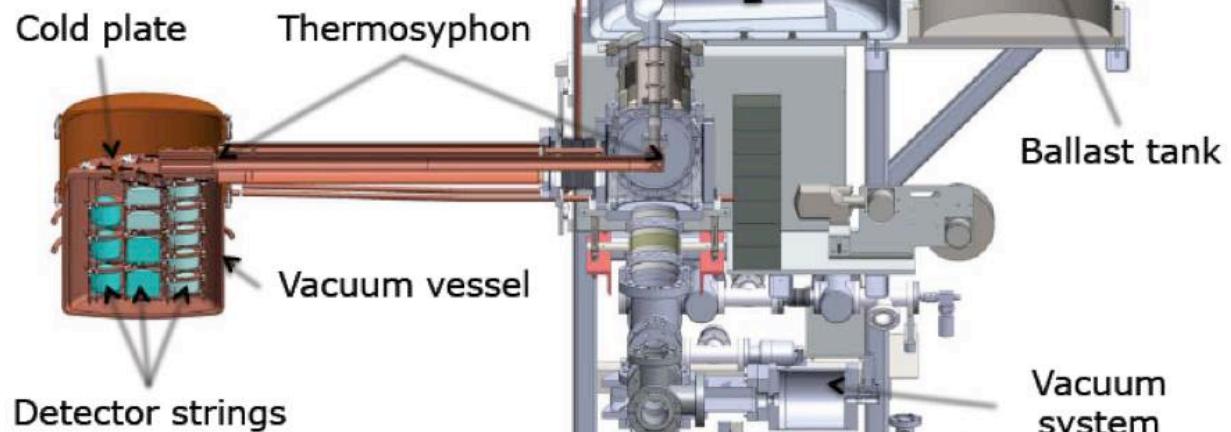


Cryogenic System



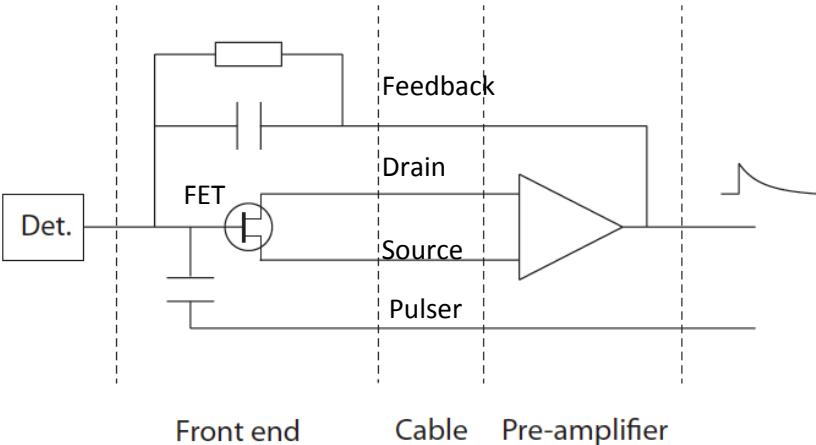
Pulse Tube
Cooler for
prototype

Pressure monitor & relief



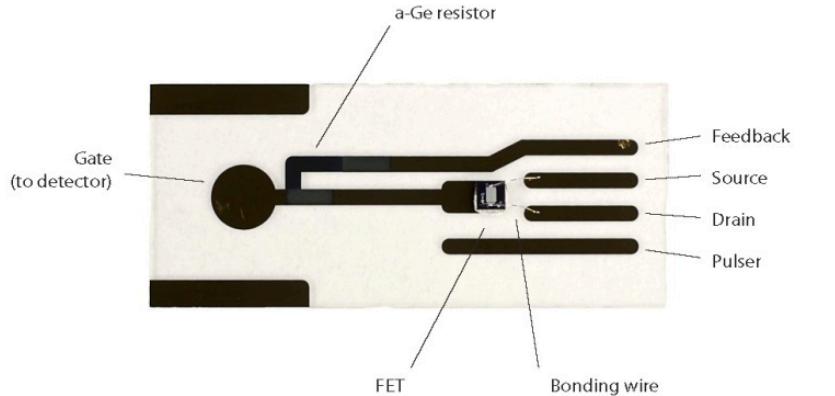


Low Mass Front End



Self heating

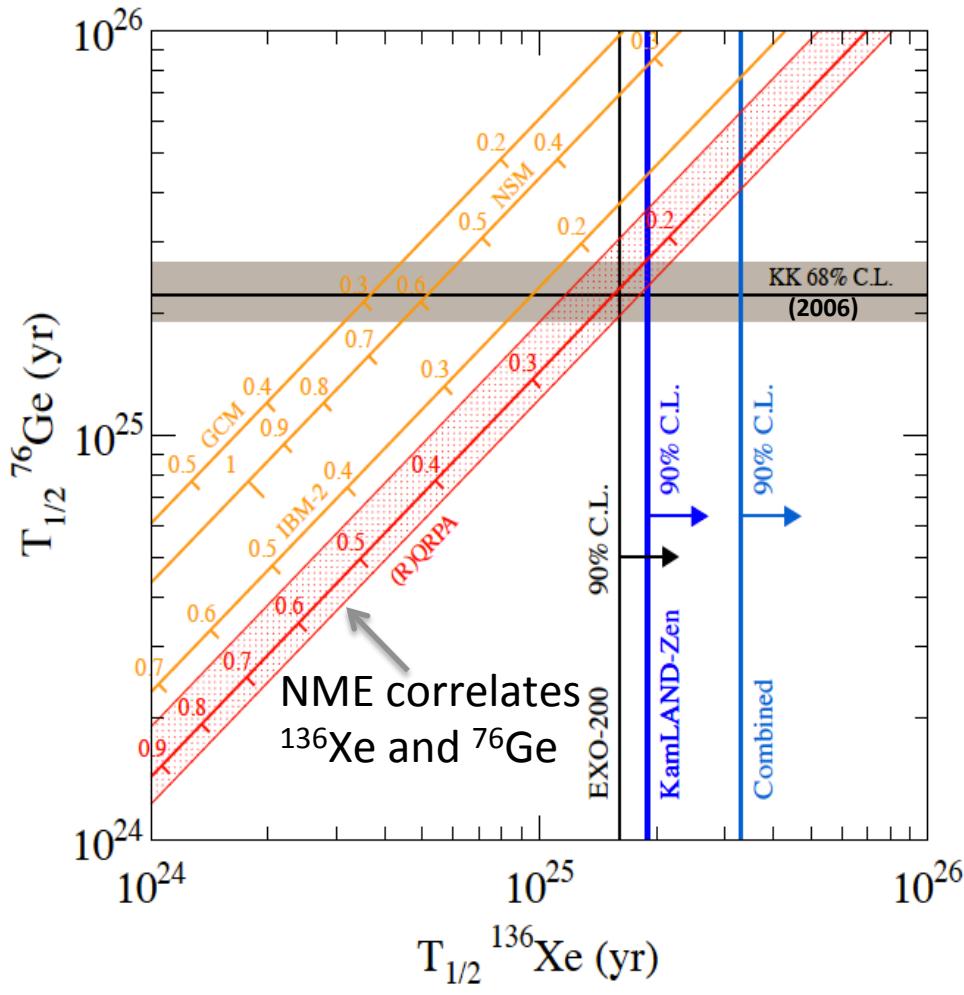
Temperature can be Controlled by Drain to Source Voltage



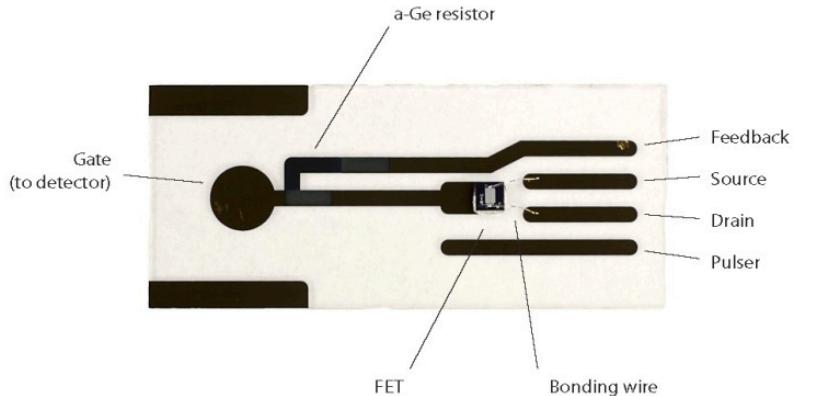
- Fused silica substrate
- Au-Cr traces
- Amorphous-Ge resistor
- Low background
- Low noise

Status prior to the most recent Ge results

Phys.Rev.Lett. 110, 062502 (2013)



Low Mass Front End



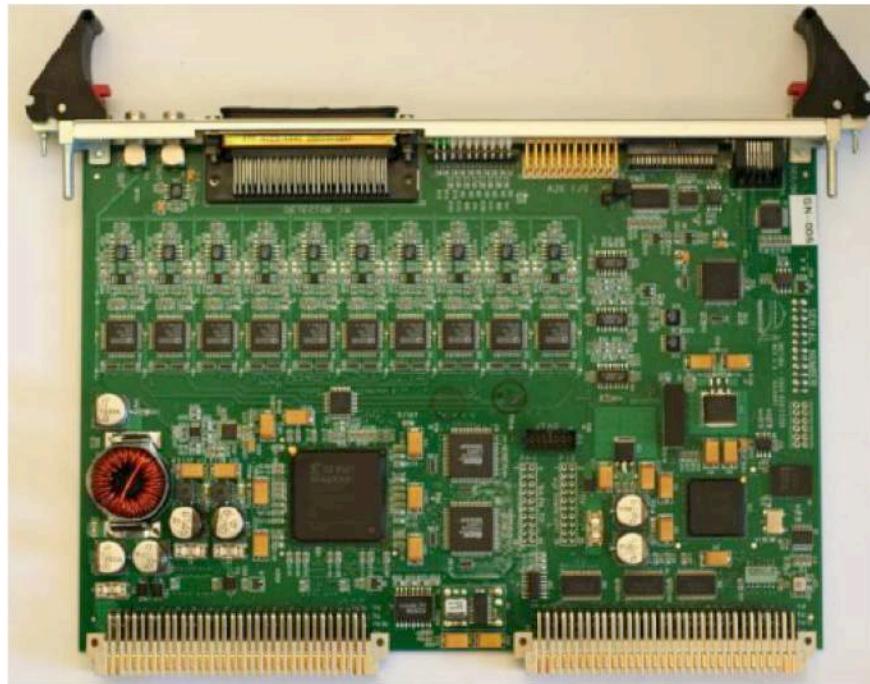
All material are selected to have low radioactivity

Component	Material	Purity (g/g)		Counts / ROI / t / y		Ref.
		^{232}Th	^{238}U	^{232}Th	^{238}U	
Substrate	Fused silica	101×10^{-12}	284×10^{-12}	0.0259	0.0616	MJ ICP-MS
Resistor	a-Ge	5×10^{-9}	5×10^{-9}	0.0001	0.0001	MJ ICP-MS
Traces	Au	$47(1) \times 10^{-9}$	$2.0(0.3) \times 10^{-9}$	0.0421	0.0015	MJ ICP-MS
Traces	Ti	$< 400 \times 10^{-12}$	$< 100 \times 10^{-12}$	~ 0	~ 0	MJ ICP-MS
FET	FET die	$< 2 \times 10^{-9}$	$< 141 \times 10^{-12}$	< 0.0107	< 0.0006	MJ ICP-MS
Bonding wire	Al	$91(2) \times 10^{-9}$	$9.0(0.4) \times 10^{-12}$	0.0004	~ 0	MJ ICP-MS
Epoxy	Silver epoxy	$< 70 \times 10^{-9}$	$< 10 \times 10^{-9}$	< 0.0685	< 0.0082	MJ gamma
Total				< 0.1476	< 0.0720	

- Fused silica substrate
- Au-Cr traces
- Amorphous-Ge resistor
- **Low background**
- Low noise



GRETINA digitizer card



Pulse-Shape-Discrimination

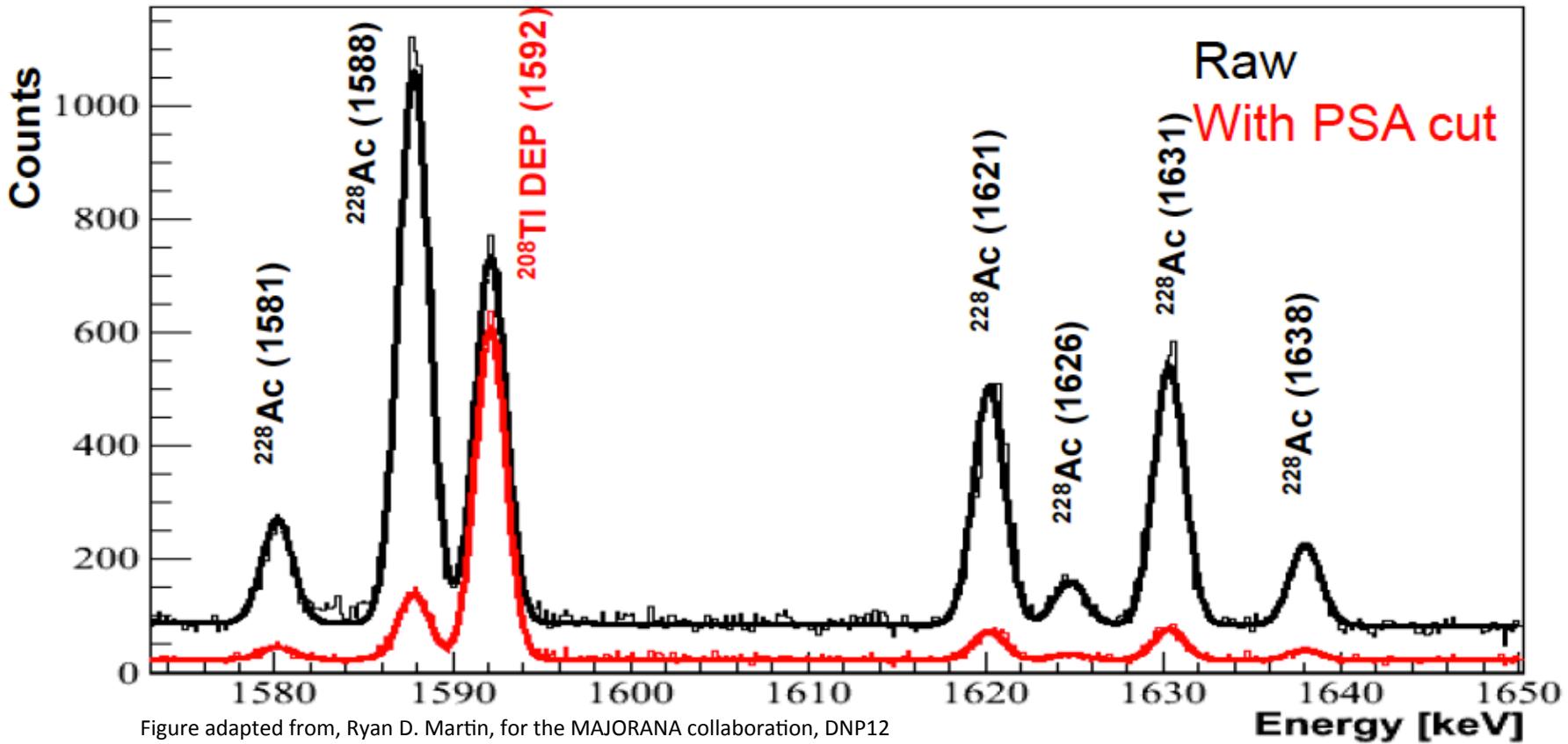
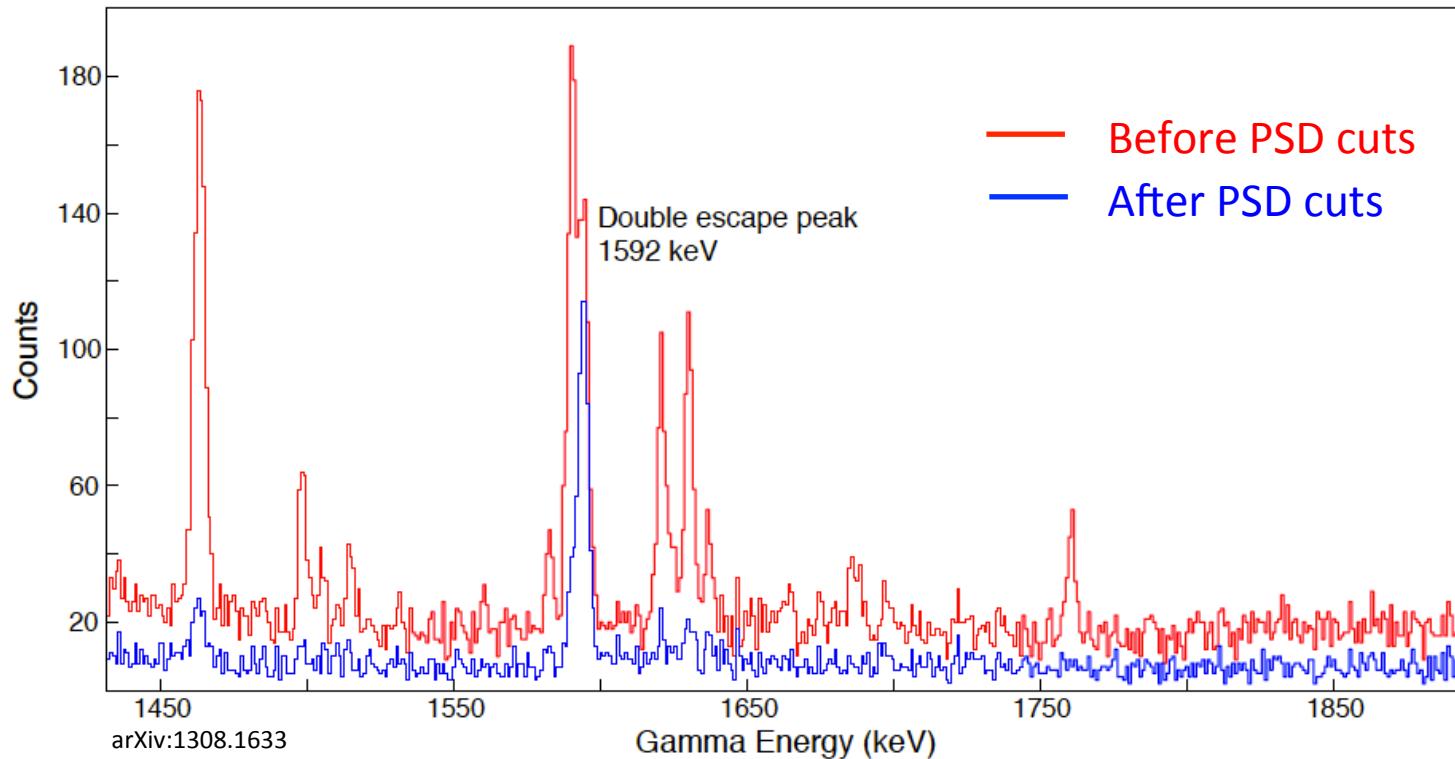


Figure adapted from, Ryan D. Martin, for the MAJORANA collaboration, DNP12

Retain 90% Double Escape Peak: single-site events, similar to $0\nu\beta\beta$ and $2\nu\beta\beta$
Reject 89% Full Energy Peaks: multi-site events, background-like

Pulse-Shape-Discrimination





Effective mass formula

the sum. The prediction is insensitive to θ_{13} and δm_{21}^2 because they are small. Setting $\theta_{13} = 0 = \delta m_{21}^2$, the following relation between M_{ee} and Σ is obtained for both hierarchies [297]:

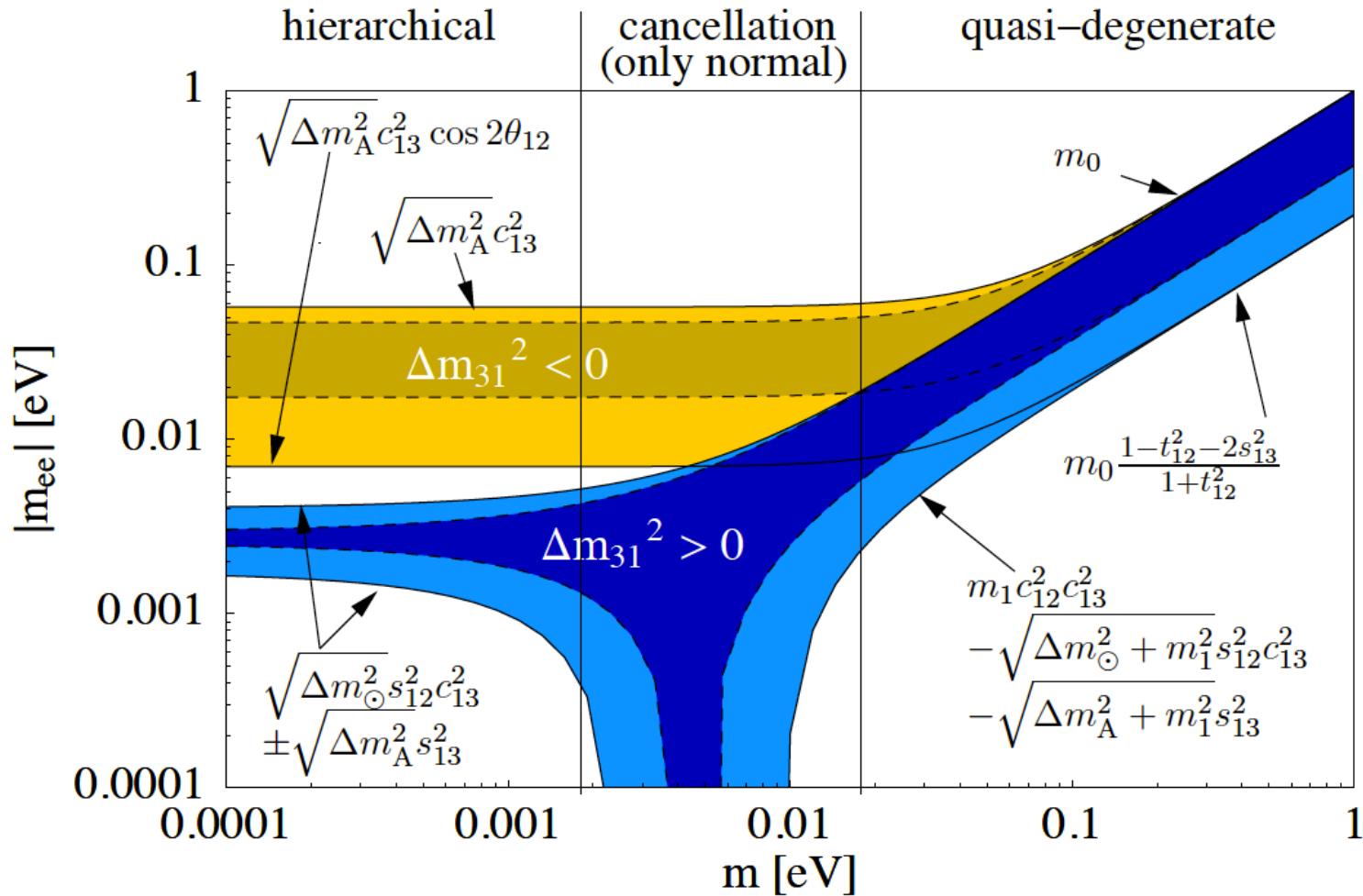
$$M_{ee} = \left(2\Sigma - \sqrt{\Sigma^2 + 3\delta m_{31}^2} \right) |c_{12}^2 + s_{12}^2 e^{i\phi}| / 3, \quad (7.8)$$

where ϕ is a Majorana phase. For a given measured value of M_{ee} both upper (since $\theta_{12} \neq \pi/4$) and lower bounds are implied for Σ . These bounds are displayed in figure 7.2. The present upper limit on M_{ee} is 0.35 eV at the 90% C.L. [301], with an overall factor of 3 uncertainty associated with the $0\nu\beta\beta$ nuclear matrix elements [302, 303]. A detection of neutrinoless double beta decay, corresponding to $M_{ee} = 0.39$ eV, has been reported [304], but this experimental result is highly controversial [305].

The physics of neutrinos, V Barger, D Marfatia, K Whisnant, 2012, Princeton University Press



The mass plot



Simulated Background near $Q_{\beta\beta}$



Simulated spectra, 60 kg yrs, detector resolution applied

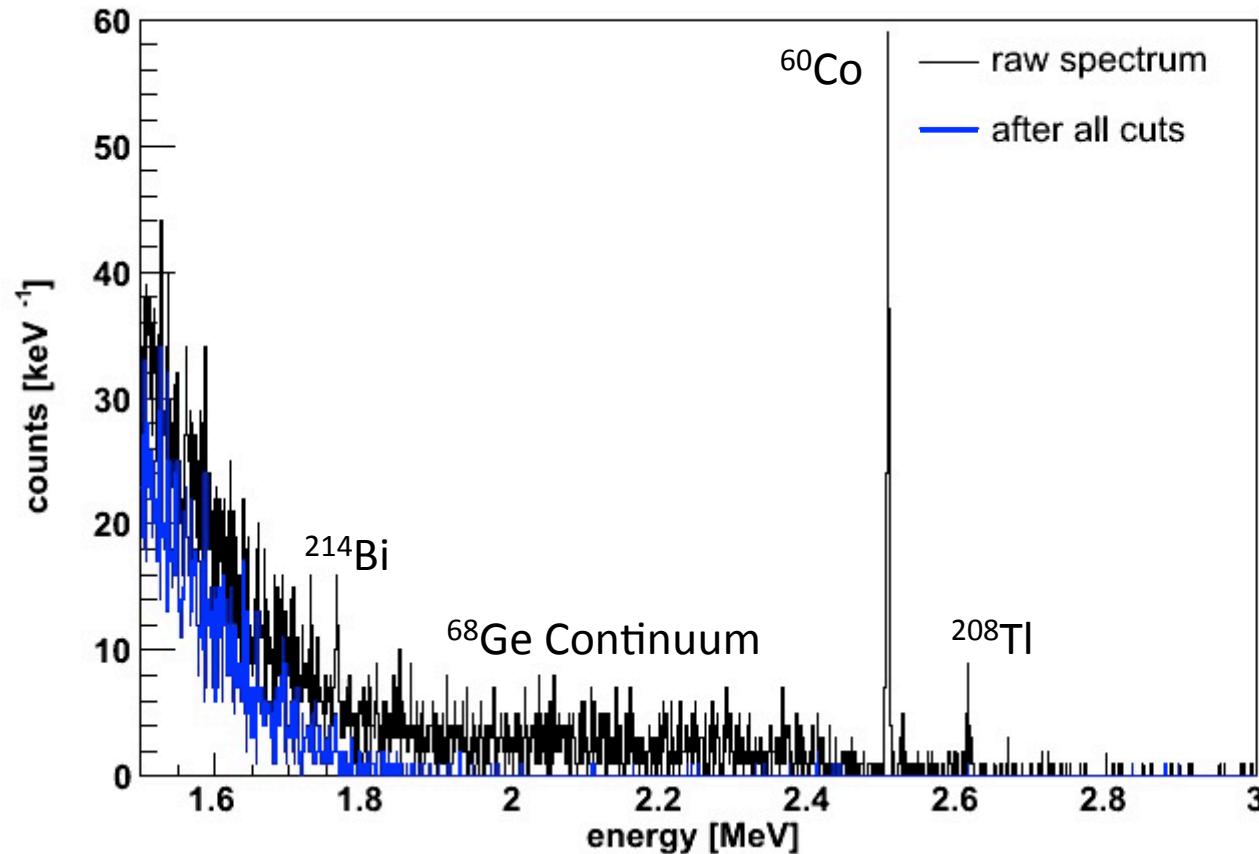


Figure adapted from
J.F.Wilkerson,
DOE ONP Comparative Review
June 25, 2013



Low background is the key

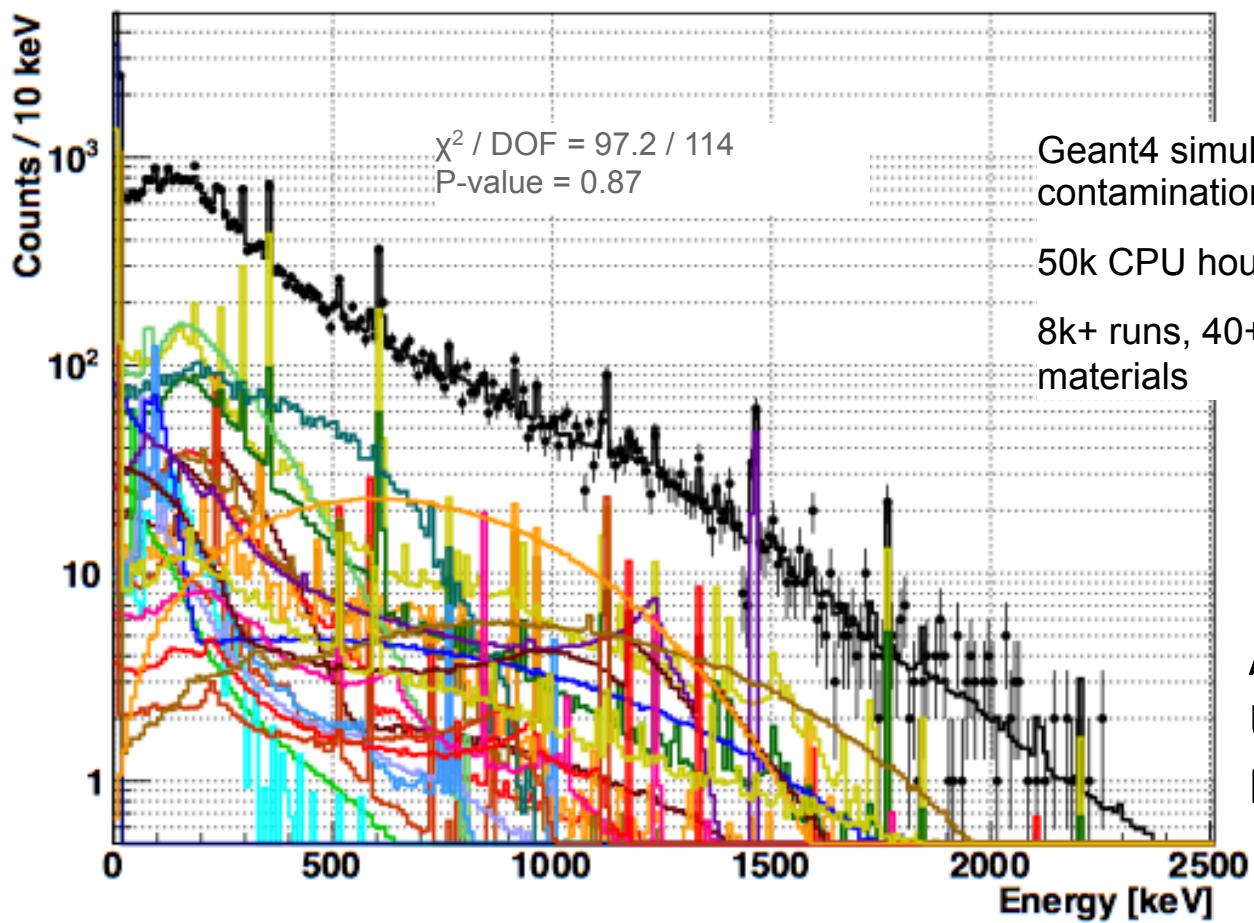
Natural radioactivity:

- **Pure material** (e.g. EFCu, clean plastic and others)
- **Shielding**
- **Analysis cuts** (PSD, granularity cuts)

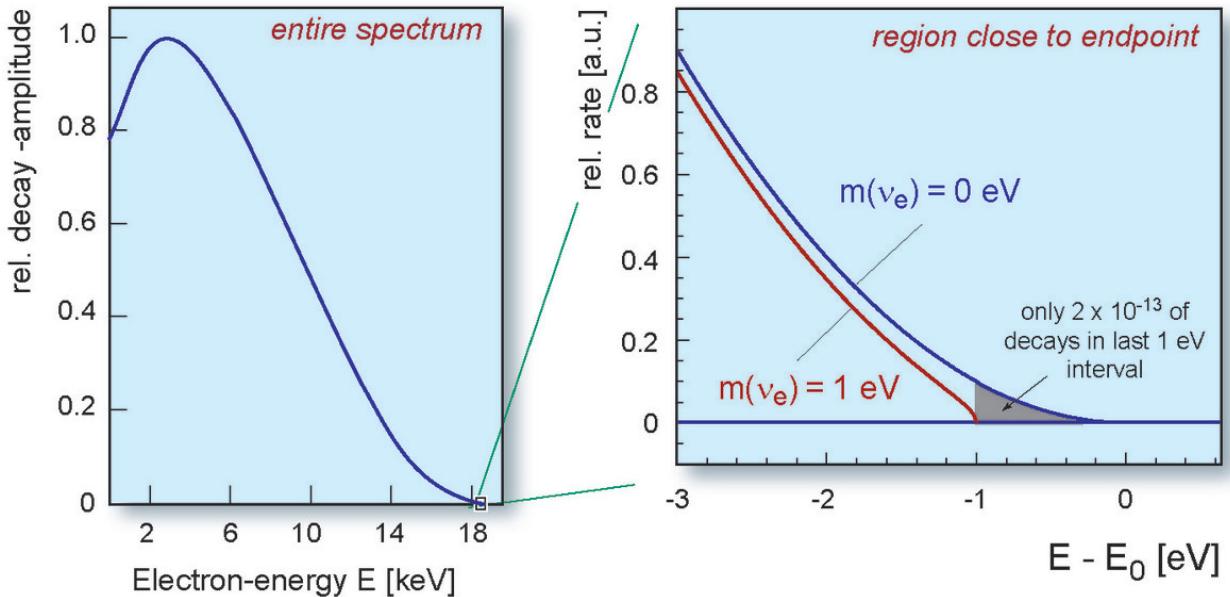
Cosmogenic:

- **Deep underground** Combined efficiency of two layers of veto panel~99.9%,
Un-vetoed direct muon background<0.03 counts/ROI/t/y.
- **Muon veto**
- **Limit surface time of Ge** (shielded shipping and storage)
- **E-form Cu underground**
- **Analysis cuts** ^{68}Ge tag Single-Site Time Correlation Cut

Background model fit of R&D Detector (MALBEK)



KATRIN sensitivity



<https://www.katrin.kit.edu/128.php>

KATRIN is expected to achieve the following sensitivities for the mass of the electron neutrino:

Sensitivity:

(90% upper limit if neutrino mass is zero)

0.2 eV with about equal contributions of statistical and systematical errors.

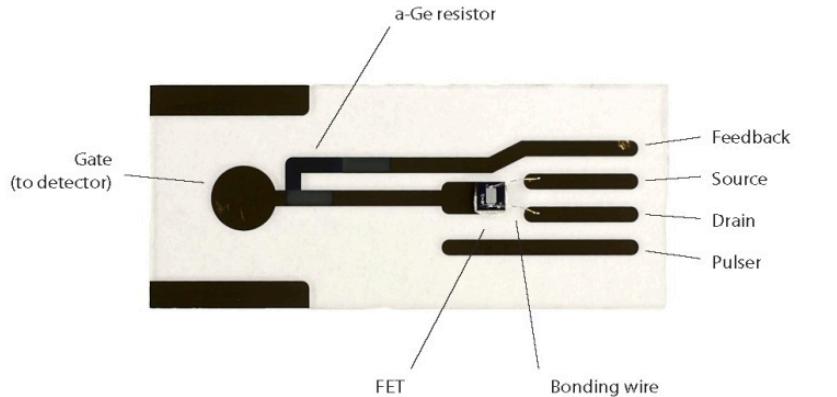
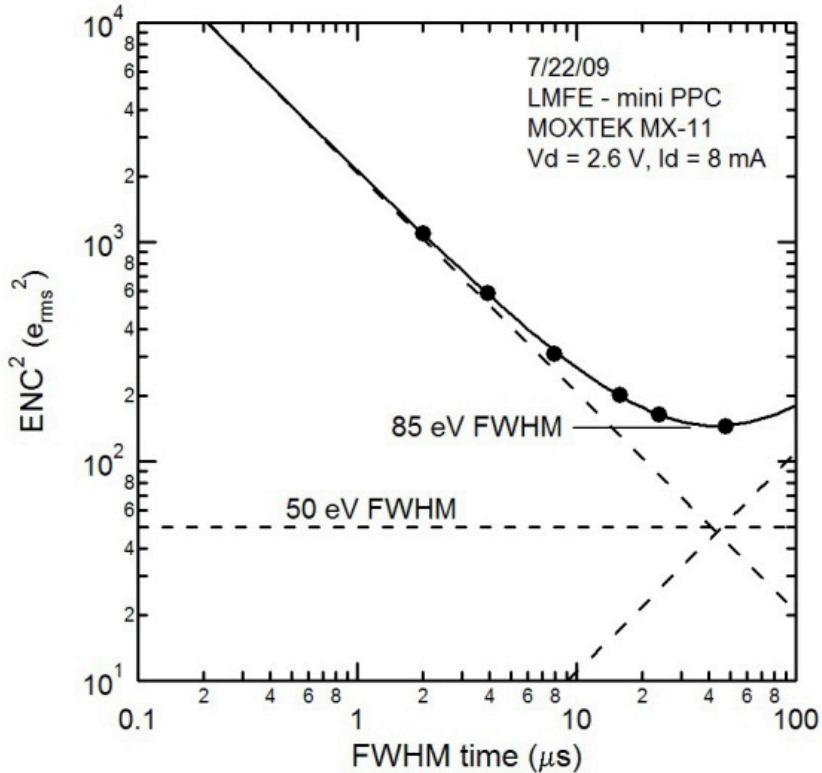
Discovery potential:

A neutrino mass of **0.35 eV** would be discovered with **5 sigma significance**.

A neutrino mass of **0.30 eV** would be discovered with **3 sigma significance**.



Low Mass Front End



- Fused silica substrate
- Au-Cr traces
- Amorphous-Ge resistor
- Low background
- Low noise**